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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
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FIGS. 1–13, JUNE, 1958

MICRO-MECHANISMS OF SEDIMENTATION IN THE EPICONTINENTAL ENVIRONMENT[1]

ALBERT V. CAROZZI
University of Illinois, Urbana, Illinois

ABSTRACT

Difficulties will always arise if we presume to compare conventional stratigraphic columns (macrolithology) with corresponding geophysical logs (responding to microvariations), because the causative phenomena are of two widely different orders of magnitude.

We should study closely-spaced thin sections, compute data on frequency and maximum apparent grain-size (clasticity index) of the principal microscopic components (detrital and authigenic minerals, benthonic and pelagic microfaunas, physico-chemical properties of the matrix), and plot these as a set of curves alongside the stratigraphic column for comparison with the geophysical profile and the zonation of the index-fossils.

Several mechanisms of sedimentation have been outlined in numerous Paleozoic and Mesozoic sections of Europe through the investigation of the following problems:

1.—Variation of the clasticity and the frequency of detrital minerals.

2.—Relations between detrital minerals and authigenic components such as glauconite, silica, and feldspars.

3.—Variation of iron compounds with respect to detrital and authigenic minerals.

4.—Variation of microfaunas with respect to mineral components.

5.—Reciprocal relations between benthonic and pelagic microfaunas.

It is suggested that microscopic investigation should become common practice because numerous processes of sedimentation of fundamental importance for the reconstruction of environments are of small scale and are commonly overlooked.

INTRODUCTION

The microscopic investigation of a sedimentary sequence appears to be the necessary complement to any field survey.

In a microscopical scale, any sedimentary rock may reveal the following components: detrital minerals in grains or flakes, authigenic minerals, benthonic and pelagic microfaunas, and a matrix. We should not only count and describe the main characteristics of the microscopic components but also trace their variation both in a vertical and horizontal direction; in order to obtain a set of curves which could be drawn alongside the stratigraphical column to supply information in addition to the lithological symbols and which could be easily compared with geophysical logs or index fossil zonation.

SAMPLING AND MEASUREMENT TECHNIQUES

An accurate sampling is indispensable for establishing precise curves. A fully oriented sample taken every foot vertically appears sufficient for the current investigation of uniform and lithologically variable sequences. However, in thin-bedded series the sampling distance should be reduced in order to provide two samples for each bed determined in the field.

It is obviously impossible to give rigid rules of sampling, and preliminary tests are always necessary to check the degree of variability of the investigated section. An almost continuous sampling would be the ideal answer, and experience has shown to us that a sampling distance of 5 inches is very near to it.

Measurements in thin-sections may be divided as follows

1. Detrital minerals—For a given detrital mineral, the largest apparent grain-size is computed after measuring about 100 grains. Under such conditions the apparent maximum diameter in thin-section (or *clasticity-index*, Carozzi, 1950–1956) is very near the real one.

For a given mineral, the number of grains or *frequency-index* is measured by computing the number of grains over a carefully determined surface of the thin-section (in the present study, 60 sq mm); it is obvious that any method of computing frequencies may be used according to the particular type of study. The clasticity index is an expression

[1] Presented at the G.S.A. Annual Meeting, Atlantic City, N. J., November 1957. Manuscript received January 8, 1958.

of the power of transportation of the currents whereas the frequency index gives an idea of the load of the same currents.

2. Authigenic minerals—As for detrital minerals, the maximum apparent diameter and the frequency of authigenic minerals are computed; however their significance is somewhat different. They indicate respectively the size reached by the growth of the authigenic crystals or grains and their number.

3. Microfaunas—Only frequency measurements are usually computed for the microfaunas. However, in particular cases, the apparent maximum diameter of individuals may be useful to check adaptations to environment, for instance. The frequency of benthonic faunas has a bathymetrical and environmental significance which is very important for the over-all interpretation of the sedimentary series. During such an interpretation a distinction should be made between the frequency of entire microfossils (ostracods, foraminifera) and the frequency of fragments of much larger fossils (inoceramas, echinoids).

4. Matrix—The amount, texture, and composition of the matrix are usually studied by combining microscopic and chemical methods.

When comparisons and correlations are tried between the curves of the different components of a sediment, not too much attention has to be given to the small details of the curves and envelop-curves should be used to smooth out local and temporary effects and reveal the main trends of variation.

GENERAL ASPECT OF THE PROBLEM

Two types of relation of the microscopic components with respect to the lithological sequence observed in the field are usually encountered:

1. The microscopic components vary in the same manner as the macrolithology; correlations are similar in both scales of observation; petrographic refinements may be introduced among beds which appear macroscopically identical.

2. The microscopic components vary independent of the macro-lithology; hence small-scale differentiations may be introduced into uniform-looking series which in the field are beyond usual criteria of sub-

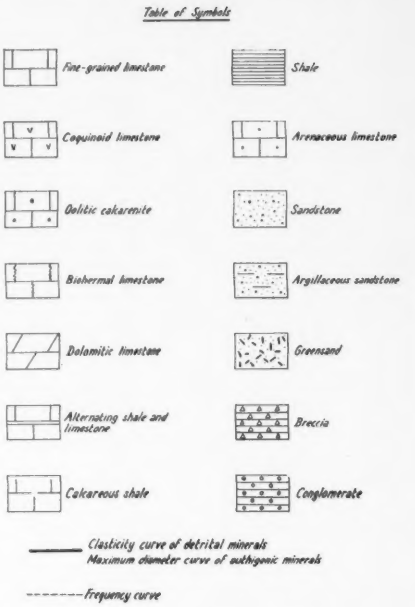


FIG. 1.—Graphic legend for figures 2–13. See also the following verbal legend.

VERBAL LEGEND

Curves without scales have the same scale as the one drawn to their left. When clasticity and frequency are computed for one component, a common scale is used in the diagrams; the first line of figures below it corresponds to the clasticity and the second line to the frequency, always given in actual figures.

Minerals

CL: clay. DQ: detrital quartz. FE: iron. FEL: authigenic feldspars. GL: glauconite. MI: micas. PH: calcium phosphate. PO: pseudoolites. SI: authigenic silica.

Organisms

Benthonic.—ANN: Annelids. ANOM: Anomalinidae. COL ORG: Colonial Organisms. DASY: Dasycladaceae. ECH: Echinoids. INOC: Inocerams. LENT: Lenticulinidae. MIL: Miliolidae. ORB: Orbitolina, OST: Ostracods. RU: Rudistids. SP: Sponges. STOM: Stomiospherids. TEXT: Textularidae.

Pelagic.—GLOBI: *Globigerina*. GLOBO: *Globotruncana*. GUMB: *Gümbelina*. OST: Ostracods. PEL CRIN: pelagic Crinoids (Saccocoma). RAD: Radiolaria. TIN: Tintinnoids.

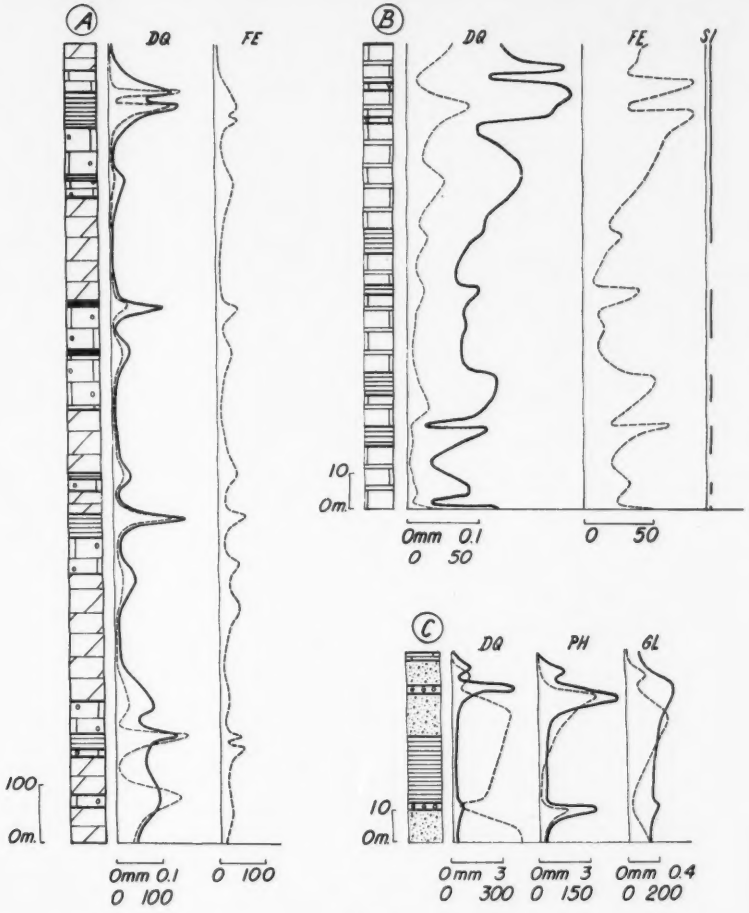


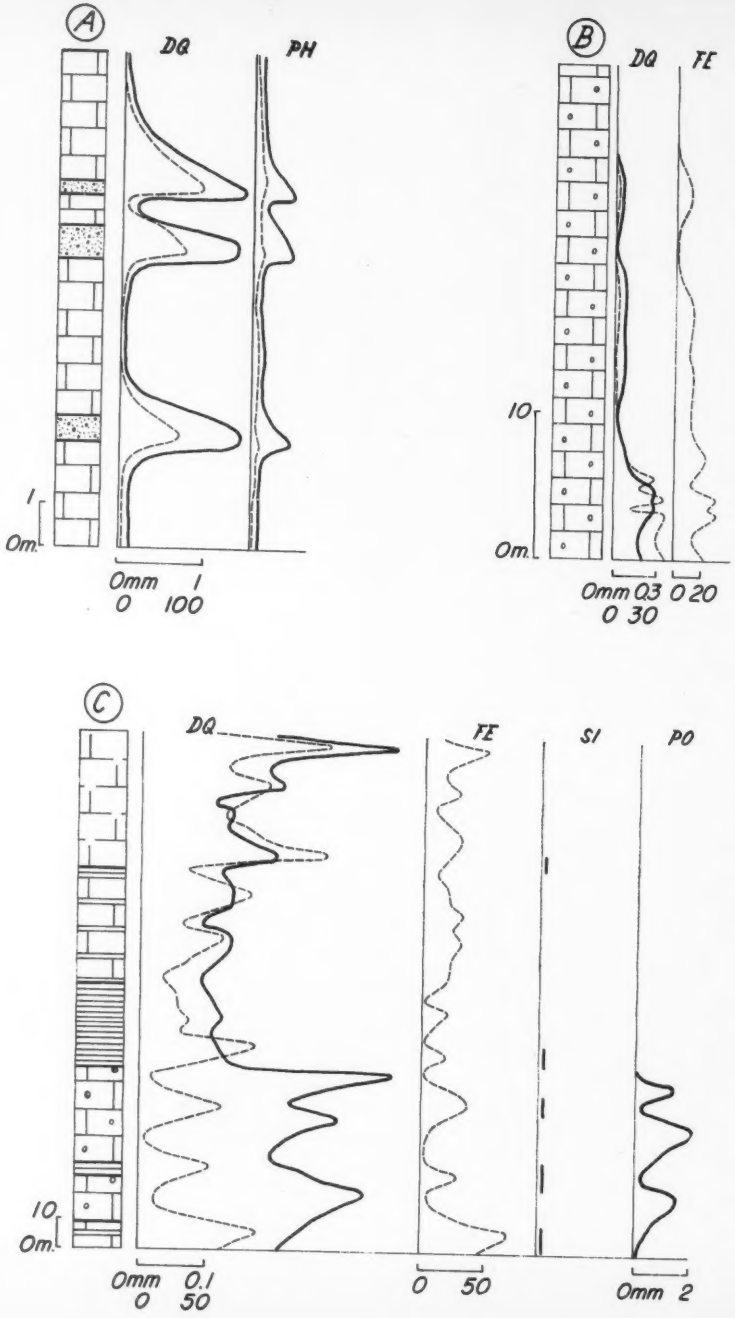
FIG. 2

A. Upper Cambrian, Mural Glacier, Jasper National Park, Canada.
B. Valanginian (Lower Cretaceous), La Giettaz, Morcles Nappe, High-Savoy, France.
C. Albian (Middle Cretaceous), Taine Pass, Autochthonous, High-Savoy, France.

division. In series with varying lithology small-scale variations are able to cross facies-boundaries; this is particularly true for detrital minerals which are distributed across an entire basin by current actions in an almost instantaneous way. The variations of the curves allow correlations between different synchronous facies; these correlations are similar to those attempted by using index fossils and may be combined with them.

When variations of such stable clastic components as detrital quartz are traced horizontally it is possible to correlate normal sedimentary rocks with their equivalents more or less modified by diagenetic processes such as dolomitization.

By drawing the variation curves of the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microscopical components alongside a stratigraphic column we increase our petrographic knowledge with precise data which are very useful for the interpretation of the environment; moreover their objective character replaces the more or less "subjective" look of microfacies and helps comparisons. According to the type of relations between micro- and macro-lithology, correlations between similar beds are confirmed or correlations between different facies or between portions of uniform sequences are provided.

Figure 1 illustrates the symbols used in figures 2–13.

CLASTIC COMPONENTS

1. Detrital minerals in grains.—Among them quartz is the most widespread and reveals two main variations:

A parallel variation of clasticity and frequency showing uniform conditions of inflow and distribution of the detrital particles which occur at any scale of observation (fig. 2A and B, fig. 3A).

An inverse variation of clasticity and frequency showing irregular conditions of inflow and distribution of the detrital grains which occurs also at any scale of observation (fig. 2C and fig. 4B).

The parallel and inverse types of variations grade into one another through transitional zones and may also alternate in the stratigraphic column (fig. 3B and C, fig. 4C). Under given current conditions, one mineral may show parallel variations and another one may show inverse variations of their clasticity and frequency indexes (fig. 2C and fig. 4A and C). When currents which bring in mineral grains lead to intraformational reworking, pseudoolites are generated and their behavior is in close agreement with the parallel or inverse variations of the accompanying minerals (fig. 3C and fig. 4C) according to the local conditions.

2. Detrital minerals in flakes.—They are mainly micas; usually their clasticity is higher than that of the associated clastic grains. When detrital inflow conditions are uniform, parallel variations of clasticity and frequency are observed as for detrital grains but curves appear less regular (fig. 5A).

When inflow conditions become irregular, the gradual increase of the current strength leads to a winnowing of the largest flakes; hence the clasticity and the frequency curves both show a minimum zone when the clasticity curves of the minerals in grains are at a peak (fig. 5B, C, and D).

AUTHIGENIC COMPONENTS

Usually the curves of maximum apparent diameter and the curves of frequency of authigenic minerals show parallel variations indicating that the authigenesis takes place in numerous spots and that individuals reach large sizes.

1. Glauconite.—The irregular shape of the glauconite grains, their internal texture showing irregular concentric rings, and their association with scattered small pigments is the first indication of the autochthonous origin. This is confirmed by the fact that the curves of maximum apparent diameter and of frequency are usually parallel and clearly opposed to the clasticity curve of the quartz (fig. 6C). Indeed, glauconite is better generated in environments of non-deposition or weak agitation. It is obvious that if the frequency of the clastic quartz varies in opposition with its clasticity, we shall notice a parallel variation of the former with the glauconite curves, but this is merely a coincidence (fig. 6B and D).

It very often happens that glauconite undergoes intraformational reworking during which the grains are gradually rounded, so that the two curves appear more and more independent. The curve of the maximum apparent diameter has become a real clasticity curve and is similar to that of the clastic quartz, for instance; the frequency curve, however, keeps its initial significance; because autochthonous generation still continues, it is clearly opposed to any maximum revealed by the clasticity curve of the detrital minerals (fig. 6A).

The formation of authigenic glauconite may eventually cease in a given area, usually because of an increase of depth. The

FIG. 3

A. Turonian (Upper Cretaceous), Chésery, Jura, France.
B. Urgonian (Middle Cretaceous), Salvadon, Morcles Nappe, High-Savoy, France.
C. Valanginian-Hauterivian (Lower Cretaceous), Pas-de-Sales, Morcles Nappe, High-Savoy, France.

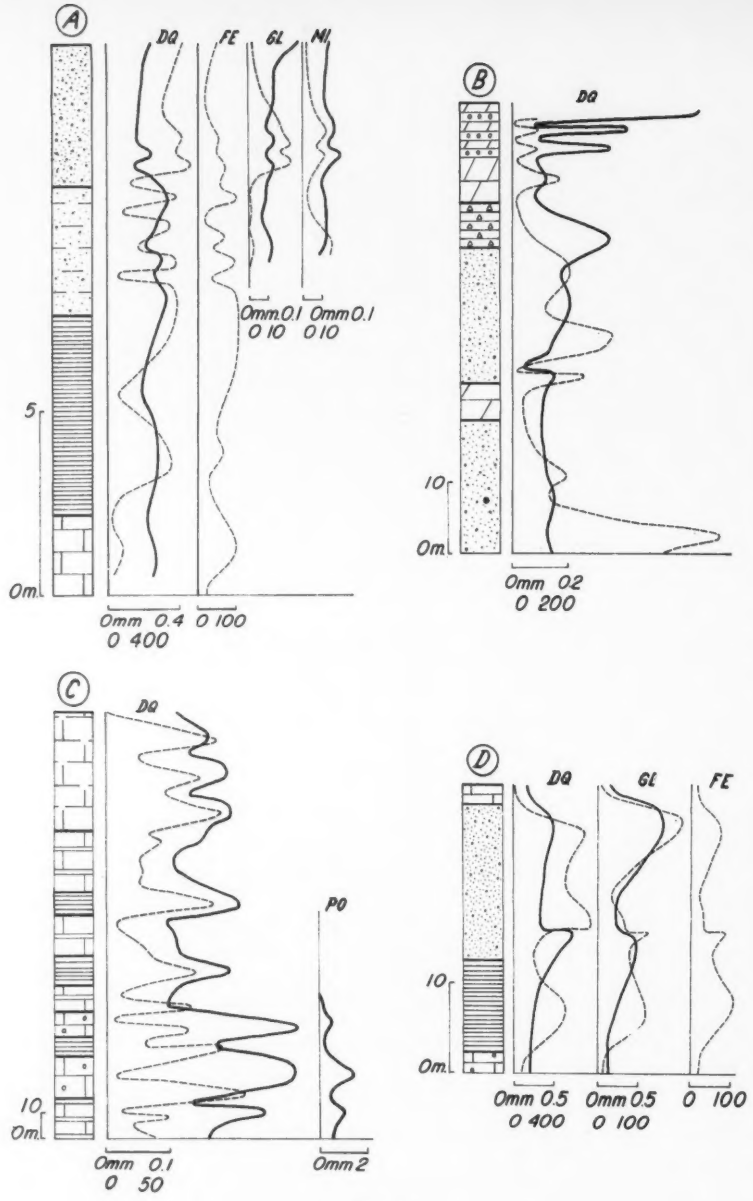

FIG. 4

A. Aptian (Middle Cretaceous), Perte-du-Rhône, Jura, France.
B. Triassic, Fiddle Creek, Jasper National Park, Canada.
C. Valanginian-Hauterivian (Lower Cretaceous), Pointe des Avaudrues, Morcles Nappe, High-Savoy, France.
D. Albian (Middle Cretaceous), Vormy, Morcles Nappe, High-Savoy, France.

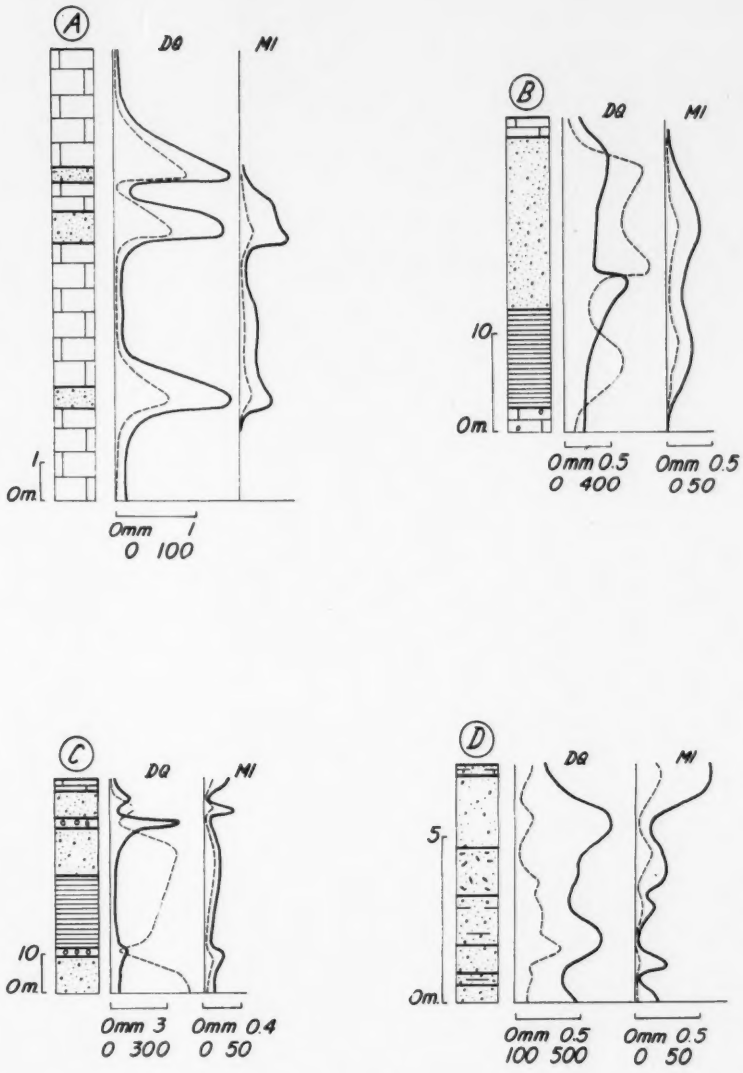

FIG. 5

A. Turonian (Upper Cretaceous), Chésery, Jura, France.
B. Albian (Middle Cretaceous), Vormy, Morcles Nappe, High-Savoy, France.
C. Albian (Middle Cretaceous), Taine Pass, Autochthonous, High-Savoy, France.
D. Albian (Middle Cretaceous), Perte-du-Rhône, Jura, France.

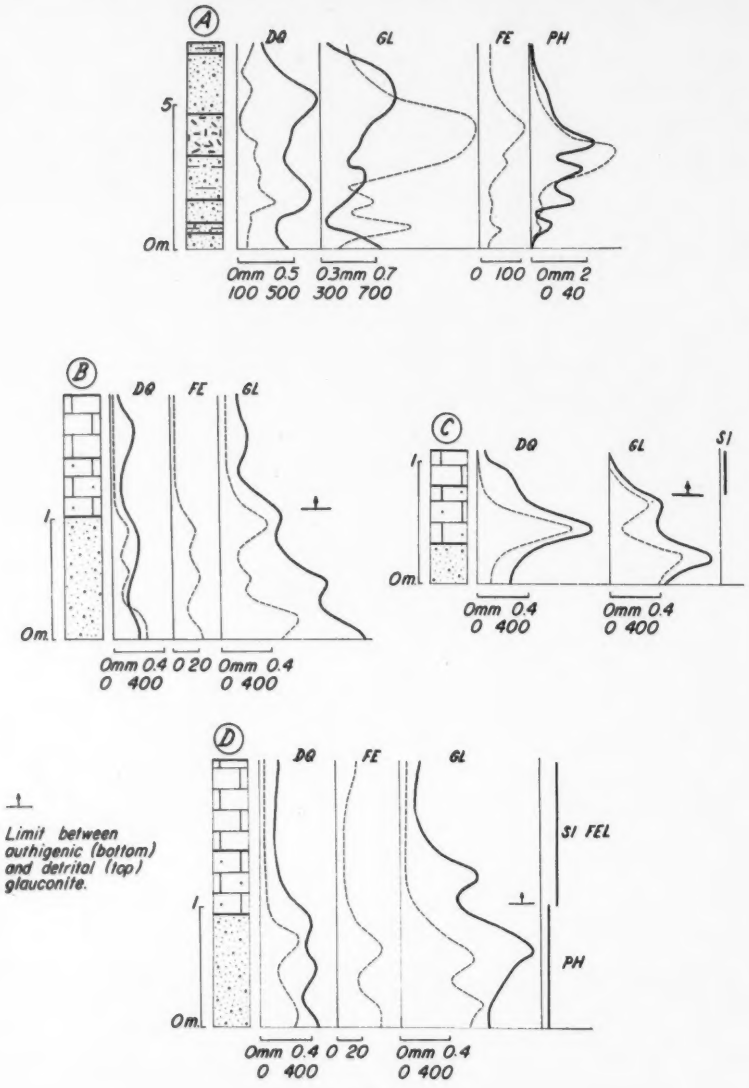

FIG. 6

A. Albian (Middle Cretaceous), Perte-du-Rhône, Jura, France.
B. Cenomanian (Upper Cretaceous), Selayre, Morcles Nappe, Valais, Switzerland.
C. Cenomanian (Upper Cretaceous), Berroy, Mrocles Nappe, Valais, Switzerland.
D. Cenomanian (Upper Cretaceous), Bossetan Pass, Morcles Nappe, Valais, Switzerland.

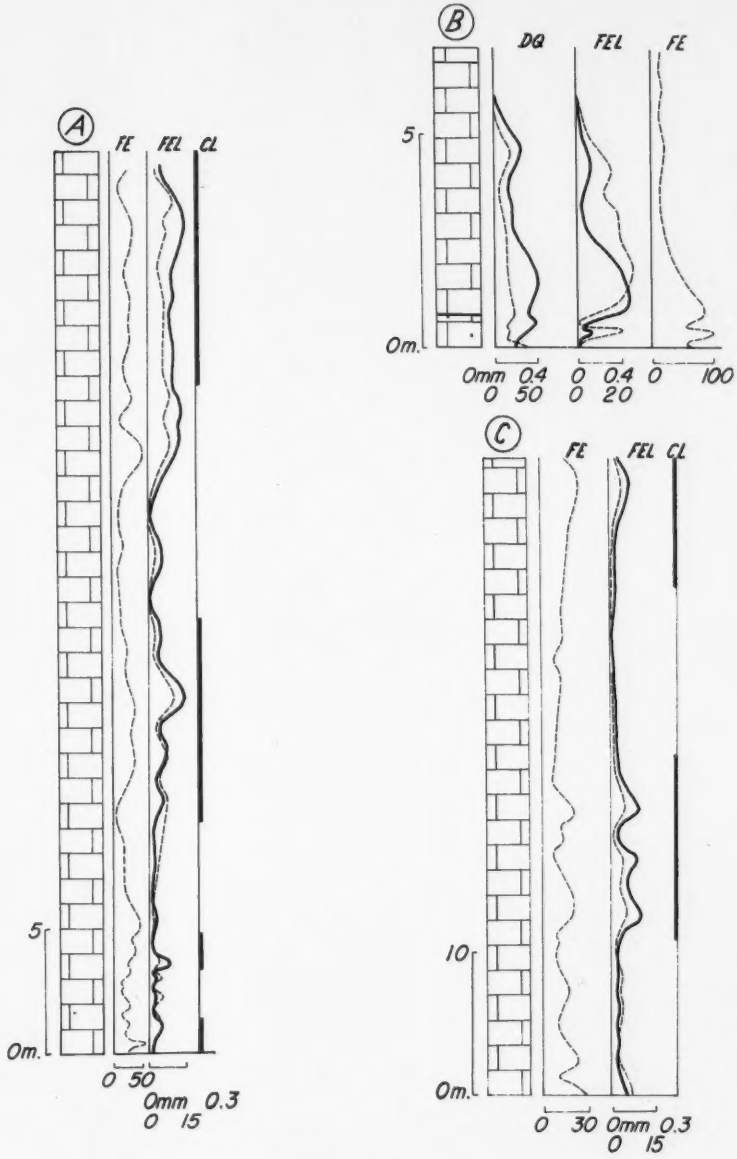

FIG. 7

A. Turonian-Senonian (Upper Cretaceous), Bossetan Pass, Morcles Nappe, Valais, Switzerland.
B. Turonian-Senonian (Upper Cretaceous), Pierre Carrée, Morcles Nappe, Valais, Switzerland.
C. Turonian-Senonian (Upper Cretaceous), Sex Rouge, Wildhorn Nappe, Valais, Switzerland.

formation of authigenic glauconite is replaced by an inflow of detrital grains of glauconite brought by the currents from the immediate neighborhood. Such a process is clearly displayed by the curves of maximum apparent diameter and of frequency which at first show inverse variations with respect to those of the detrital minerals and which gradually tend to identify themselves to the latter (fig. 6B and D).

When authigenic glauconite is locally replaced by its detrital variety, new authigenic components appear in the transitional layers: quartz or chalcedony, if clay content is low, or feldspars when clay content is high. The physico-chemical conditions having changed, it looks as if the end of the glauconite synthesis had liberated chemical constituents which from then on would be combined in another way (fig. 6D).

2. Iron.—Only frequency measurements are usually computed for the pigments of hydroxides and sulfides commonly present in the sedimentary rocks. The frequency measurements are generally made through a combination of microscopic and chemical analysis. In the present study iron content is expressed by a scale in which 10 units represent approximately 0.1 percent Fe_2O_3 in weight.

The chemical condition of the iron is largely an expression of the last sedimentation environment and its continental origin may not always be directly expressed in its behavior. For instance, when iron is brought into a basin as a colloidal hydroxide by the same currents which carry the detrital grains, we observe definite parallel variations between the curves of frequency of the quartz and the iron; such a variation can be clearly checked when the detrital inflow changes from uniform to irregular or vice-versa (fig. 2A and B, fig. 3B and C, fig. 4A and D).

Sometimes the frequency of the iron compounds is no longer related to the clastic minerals; iron is apparently precipitated from seawater mainly as iron sulfide through bio-chemical processes. Favorable conditions are similar to those of authigenic glauconite and the frequency curves of the two minerals are parallel under those conditions (fig. 6A).

3. Silica.—The same currents which bring detrital minerals and colloidal iron are also able to carry colloidal silica. In several cases the distribution of authigenic quartz or chalcedony appears related with the maximal zones of iron content and of the frequency of detrital grains (fig. 2B and fig. 3C). In other cases, silica is no longer related to any mineral component; it has undergone biological cycles and appears in close agreement with the frequency of diatoms, Radiolaria or siliceous sponges.

4. Calcium phosphate.—Calcium phosphate usually forms small nodules closely associated with authigenic glauconite which tend to disappear or are strongly reduced when the former is replaced by its detrital variety (fig. 6D). Intraformational reworking is a common feature of phosphatic facies and the curves of maximum apparent diameter and of frequency may display independent variations similar to those already described for the glauconite (fig. 6A).

5. Feldspars.—Feldspars are primarily formed during the compaction by diagenetic evolution of the clay fraction of the sediments. This synthesis, although appearing very widespread under the microscope, does not affect to a large extent the clay content of the sediments; in other words the two curves of the feldspars, and particularly the frequency curve, are still an expression of the clay content of the sediment. As the latter is directly related to the inflow of detrital grains, colloidal iron, and silica, an interesting parallelism may be noticed between such a group of detrital and authigenic components (fig. 7A, B, and C).

MICROFAUNAS

Microfaunas may be subdivided into benthonic and pelagic components which usually reveal opposed frequency variations in time and space (fig. 12A, B, and C). The inverse variation in the frequency of benthonic and pelagic microfaunas is considered as an indication of variation in water depth in a stable epicontinental environment. We feel that these biological criteria are the only ones valid for a bathymetrical interpretation, and that the data obtained from the detrital and authigenic minerals are to be interpreted in accordance with the faunal behaviors. Thus where benthonic components are most abundant and where pelagic faunas are most rare the environment may have been shallow, whereas the great abundance

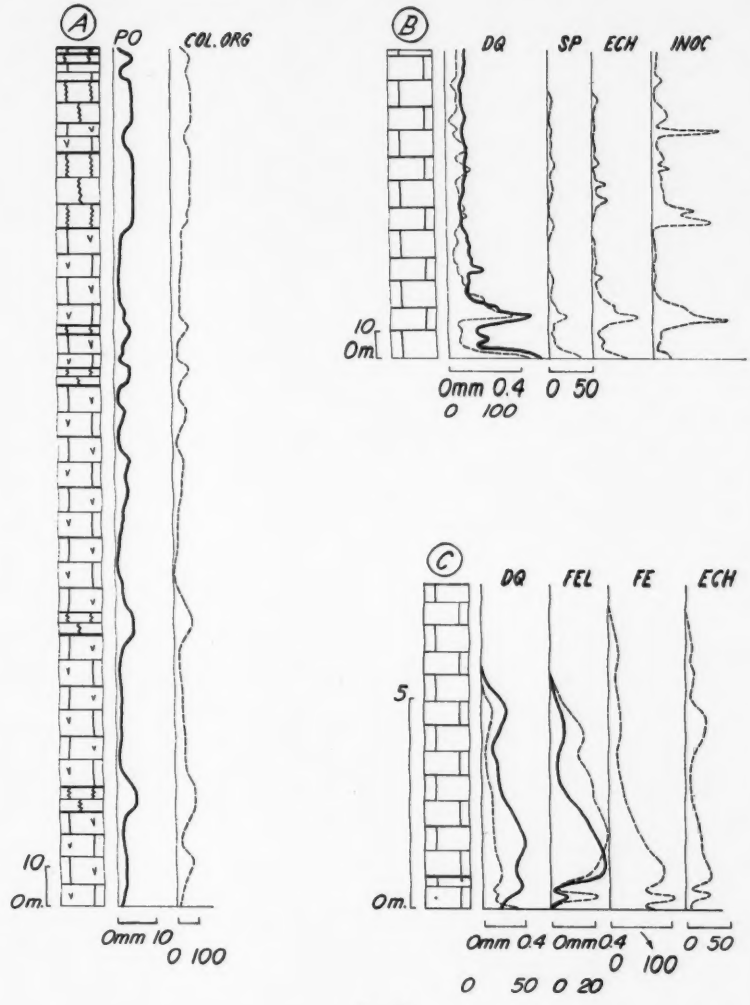

FIG. 8

A. Sequanian-Kimeridgian-Portlandian (Upper Jurassic), Salève, Jura, High-Savoy, France.
B. Turonian-Senonian (Upper Cretaceous), Châtelard-en-Bauges, Autochthonous, Savoy, France.
C. Turonian-Senonian (Upper Cretaceous), Pierre Carrée, Morcles Nappe, Valais, Switzerland.

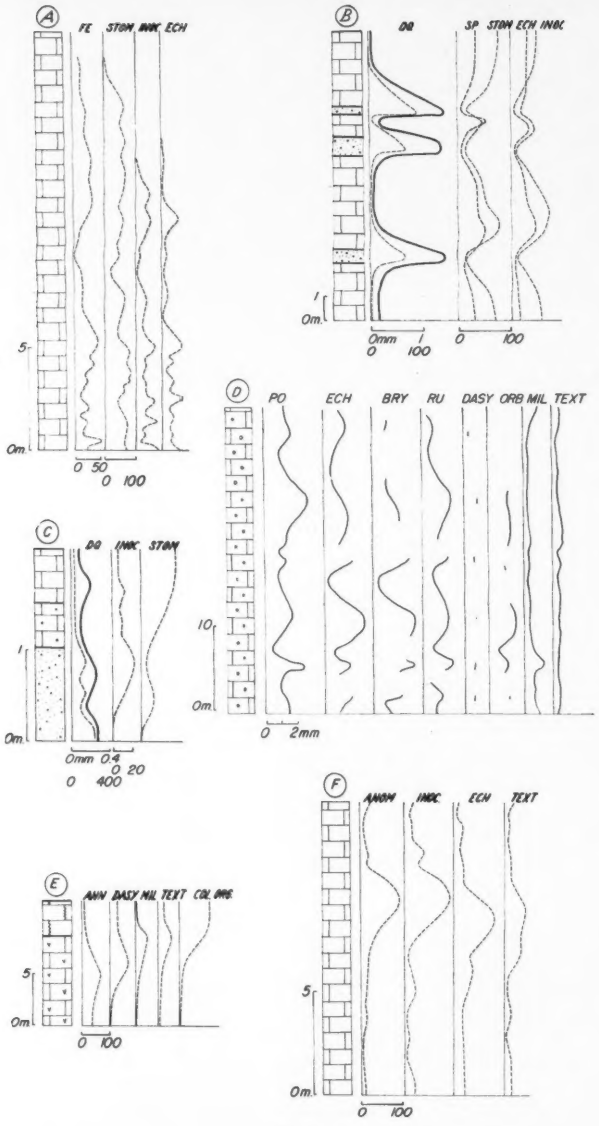

FIG. 9

A. Turonian-Senonian (Upper Cretaceous), Bossetan Pass, Morcles Nappe, Valais, Switzerland.
B. Turonian (Upper Cretaceous), Chésery, Jura, France.
C. Cenomanian (Upper Cretaceous), Selayre, Morcles Nappe, Valais, Switzerland.
D. Urgonian (Middle Cretaceous), Pas-de-Sales, Morcles Nappe, High-Savoy, France.
E. Kimeridgian (Upper Jurassic), Salève, Jura, High-Savoy, France.
F. Turonian (Upper Cretaceous), Roc-de-Chère, Autochthonous, High-Savoy, France.

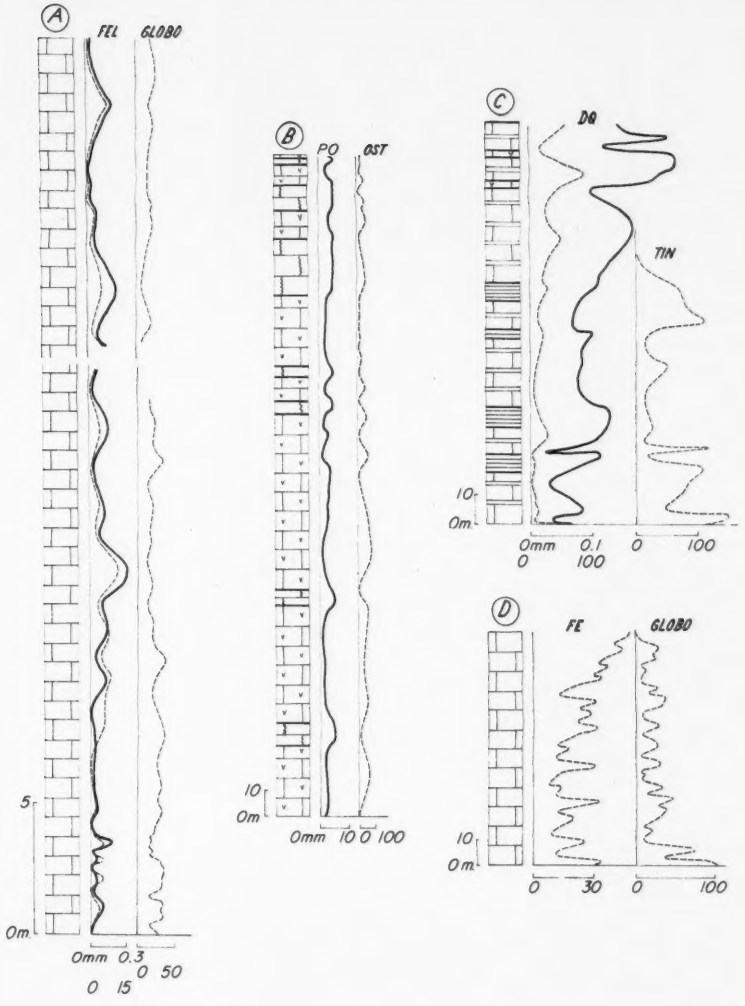

FIG. 10

A. Turonian-Senonian (Upper Cretaceous), Bossetan Pass, Morcles Nappe, Valais, Switzerland.
B. Sequanian-Kimeridgian-Portlandian (Upper Jurassic), Salève, Jura, High-Savoy, France.
C. Valanginian (Lower Cretaceous), La Giettaz, Morcles Nappe, High-Savoy, France.
D. Turonian-Senonian (Upper Cretaceous), Vormy, Morcles Nappe, High-Savoy, France.

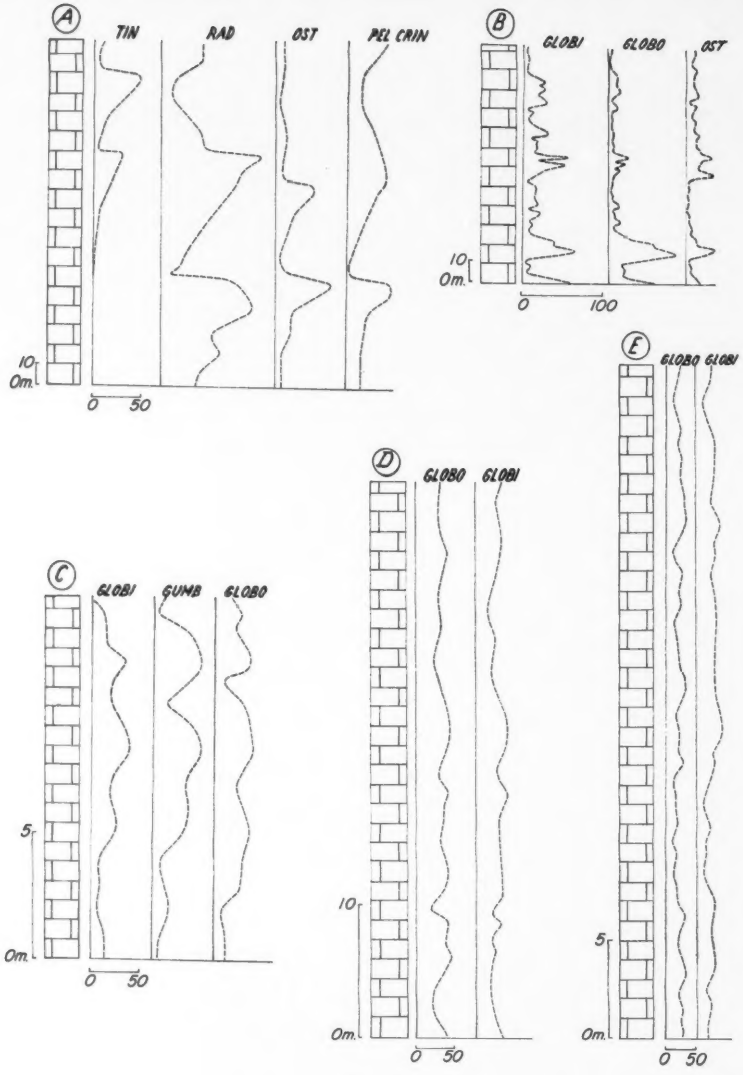

FIG. 11

A. Malm (Upper Jurassic), Commune, Morcles Nappe, High-Savoy, France.
B. Turonian-Senonian (Upper Cretaceous), Châtelard-en-Bauges, Autochthonous, Savoy, France.
C. Turonian-Senonian (Upper Cretaceous), Roc-de-Chère, Autochthonous, High-Savoy, France.
D. Turonian-Senonian (Upper Cretaceous), Sex Rouge, Wildhorn Nappe, Valais, Switzerland.
E. Turonian-Senonian (Upper Cretaceous), Bossetan Pass, Morcles Nappe, Valais, Switzerland.

of pelagic faunas associated with a paucity of benthonic forms may indicate open-ocean environment with depth conditions greatly reducing the development of benthonic microfaunas. The variation of detrital and authigenic minerals points quite commonly to the same general interpretation.

Benthonic Microfaunas

The frequency of benthonic microfaunas increases when depth decreases, and since the detrital inflow also often increases in grain-size and frequency along the same direction, a striking parallelism may be observed between the curves of frequency of benthonic components such as sponges, echinoids, inocerams, stomiospherids and the group of the clastic minerals and related authigenic components (fig. 8B and C, fig. 9A).

In the coral-reef environment, the frequency of colonial organisms (corals, bryozoans and stromatoporoids) increases in the zones of strongest wave agitation, and a parallelism is apparent with the curve of clasticity of the pseudoolites generated by wave action (fig. 8A).

The agitation of the environment, as shown by the grain-size of the detrital minerals and the amount of inflow shown by the frequency curves, bears a definite influence on several types of benthonic faunas. For instance, under moderate conditions of agitation and inflow inocerams apparently survive very well, and their frequency varies with the quartz clasticity; associated stomiospherids, on the other hand, show an entirely inversed variation (fig. 9C).

Under strong conditions of agitation and inflow both the stomiospherids and the inocerams vary in an abnormal way; their curves of frequency steadily display inverse variation with respect to the clasticity and frequency of the clastic minerals; hence the variation of these benthonic components becomes parallel to that of the pelagic microfaunas (*Globotruncana* and *Globigerina*) which normally show inverse variation with respect to the detrital minerals (fig. 13A).

When extreme conditions of agitation and inflow are reached, the whole set of benthonic components (as well as the pelagic sometimes) disappear either because the environment is unfavorable to their survival or because the shells have been ground up by the abrasive action of the detrital grains (fig. 9B).

The interpretation of the environment must not rely on single benthonic components but on faunal associations. These are clearly displayed by the similar variation of the frequency curves (fig. 9F). Successive maxima of frequency in time or space are of important ecological significance when related to facies changes (fig. 9E).

The interpretation of environment is based on the assumption that benthonic components have lived in place under normal ecological conditions. Reworked microfaunas complicate the investigation of many calcarenites.

Transported benthonic components appear as complete individuals or fragments sorted according to their size into pseudofaunas entirely devoid of environmental significance.

Traces of abrasion are present on larger individuals but are usually absent on many small ones transported in suspension. Under such circumstances, benthonic components may be assimilated to detrital minerals (or pseudoolites); indeed striking parallel variations are noticed between their clasticity and frequency curves (fig. 9D).

Pelagic Microfaunas

The frequency of the pelagic organisms commonly increases with depth until it reaches a stable value. It also happens that the clastic minerals often decrease in grain-size and in frequency in the same direction. In such a case the curves of frequency of pelagic microfaunas display variations which are entirely inverse with respect not only to benthonic components as already described but to clastic minerals, to the iron, and to all the related authigenic components.

Striking examples are those in which tintinnoids are opposed to detrital quartz (fig. 10C), *Globotruncana* to iron (fig. 10A) and to authigenic feldspars (fig. 10D).

In the coral-reef environment the frequency of the ostracods clearly displays inverse variation with respect to the general clasticity and to the reef-constructed limestone portions of the section (fig. 10B).

As for benthonic components, faunal associations are widespread among pelagic organisms and the similarity in the variation

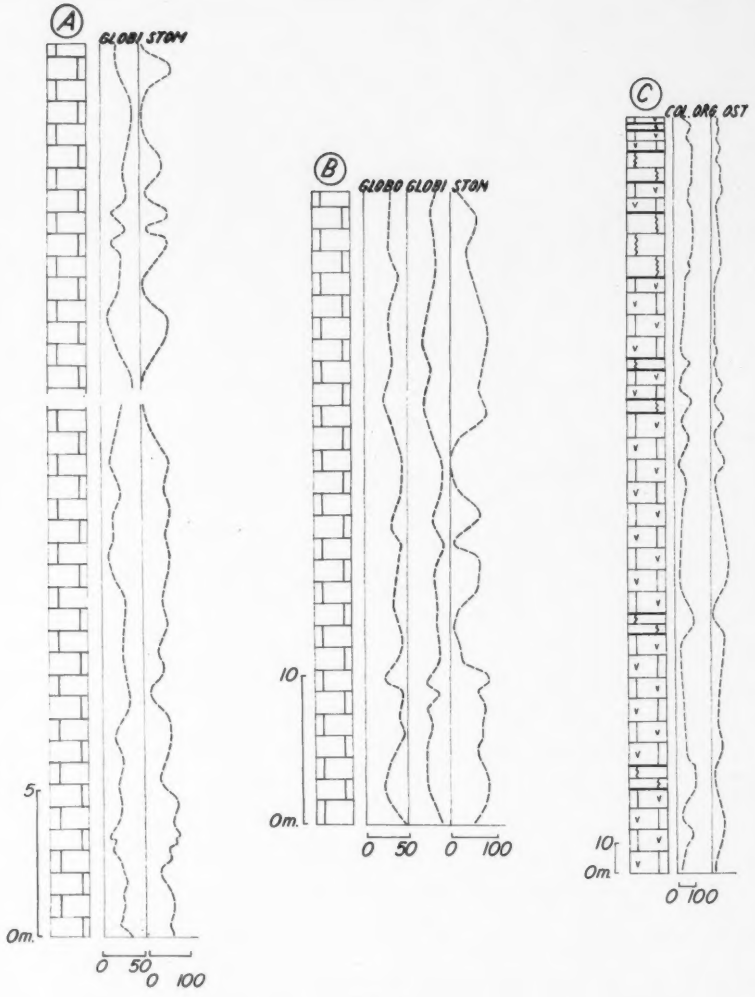

FIG. 12

A. Turonian-Senonian (Upper Cretaceous), Bossetan Pass, Morcles Nappe, Valais, Switzerland.
B. Turonian-Senonian (Upper Cretaceous), Sex Rouge, Wildhorn Nappe, Valais, Switzerland.
C. Sequanian-Kimeridgian-Portlandian (Upper Jurassic), Salève, Jura, High-Savoy, France.

f the frequency curves is even more strik-g; typical examples are the association of *lobotruncana, Globigerina, Gümbelina* and stracods (fig. 11B, C, D, and E) and by ie association of tintinnoids, Radiolaria, *ccocoma* (pelagic crinoids) and ostracods g. 11A).

The reciprocal exclusion, both in time and ace, of benthonic and pelagic microfaunas interesting not only for its ecological sig-ficance but also for its relations to the in-ow of detrital minerals and to the genesis of thigenic components (fig. 10A, C, and D). mong Foraminifera, the inverse variation etween the stomiospherids and the group *lobotruncana-Globigerina* is a common ob-rvation in Upper Cretaceous sediments g. 12A, B and C).

Pelagic components are able to show ab-ormal variation more frequently than ben-nonic organisms because of their easy and assive dispersal by marine currents. One of ie main phenomena is the mechanical con-ntration by wave and current action along ie shoreline; it is usually accompanied by acking of broken individuals in minute nses and strong deformation and local dis-olution of the tests.

The abnormal conditions are shown in the equency curves by maxima which are arallel to those displayed by the benthonic mponents and the detrital minerals in-ead of displaying inverse variations. In me cases the abnormality may be limited nly to given pelagic components and may st a very short time (fig. 13B); these con-tions are clearly displayed when the curves e compared to one another.

In other instances, however, the mechan-al concentration affects all the pelagic mponents of a sequence for a long time in-rval affording a very peculiar parallelism etween the frequency of the pelagic and enthonic microfaunas and the curves of the etrital minerals (fig. 13C).

The interpretation of microfaunas may be mplicated by the fact that certain organ-ms include genera having benthonic or elagic behavior and which are often impos-ble to distinguish during a current routine vestigation in thin-section. This is cer-inly the case for ostracods which appear as elagic components in most of our examples g. 10B, fig. 11A and B, fig. 12C) but ap-ear as benthonic in two of them (fig. 13B nd C).

Globotruncana appears typically in all our

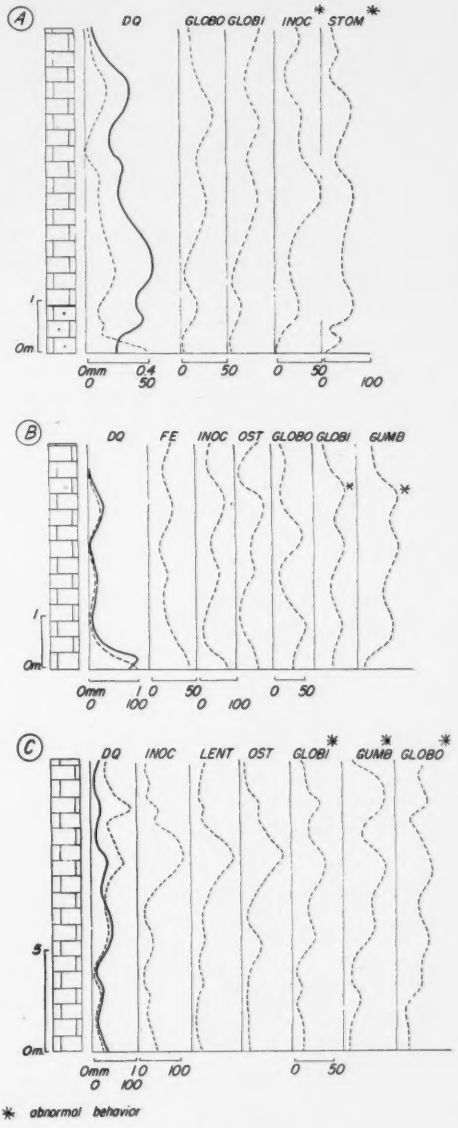

FIG. 13

A. Turonian-Senonian (Upper Cretaceous), Pierre Carrée, Morcles Nappe, Valais, Switzerland.
B. Turonian-Senonian (Upper Cretaceous), Autochthonous, High Savoy, France.
C. Turonian-Senonian (Upper Cretaceous), Roc-de-Chère, Autochthonous, High Savoy, France.

sections as a pelagic component as does *Globigerina* (fig. 10A and D, fig. 11B to E, fig. 12B). We have seen that a parallelism with benthonic components appears only when *Globotruncana* is concentrated mechanically by wave and current actions; such conditions are shown in the microfacies by changes of the lithographic limestones into fine-grained zones of calcarenites.

Edgell (1957) has found in the Upper Cretaceous of northwest Australia that the same genus displays a frequency curve which apparently resembles that of a benthonic component. In other words *Globotruncana* is abundant where other benthonic genera (such as *Anomalina* and *Cibicides*) are abundant but it is not so frequent where thin-shelled pelagic species of *Globigerina* and *Rugoglobigerina* are most common.

The same author finds further confirmation of the benthonic nature of *Globotruncana* in its morphological characters.

The interpretation of the frequency curve of *Globotruncana* given by Edgell (fig. 4, p. 107) is questionable. Sampling appears to us insufficient for drawing a reliable curve; the latter has a relatively small range of variation, and does not reveal for instance the high peak (sample GC 303) shown by the frequency curves of *Cibicides constrictus* and of the benthonic Foraminifera; moreover it seems to be affected by the minimum displayed by the frequency of *Rugoglobigerina* and by the planktonic Foraminifera in the same sample.

The frequency curve of *Globotruncana* appears to be a composite of both benthonic and pelagic behavior indicating temporary mechanical concentration which is to be expected in a clastic sediment like the Korojon calcarenite.

More unquestionable investigations in non-clastic sediments are needed before postulating that *Globotruncana* could behave as a benthonic form. Morphological characters are in no way opposed to a pelagic nature of *Globotruncana* since it is possible to check their gradual appearance through the Upper Cretaceous series without apparent changes in ecology.

CONCLUSIONS

Thin-section studies of the variations of the maximum apparent diameter and frequency of detrital minerals give numerous data on subaqueous currents. A similar investigation of authigenic minerals reveals their genetical relations to detrital inflow and environmental conditions.

Frequency measurements of benthonic and pelagic microfaunas furnish bathymetrical criteria for the interpretation of the data obtained from the detrital and authigenic minerals. Problems presented by the effects of transportation of microfaunas are analyzed.

All these microscopic data, as well as the results of chemical analyses, are plotted in a set of curves alongside the stratigraphic column to provide a more accurate tool for correlation.

ACKNOWLEDGMENTS

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FIGS. 1–9, JUNE, 1958

PROBABILITY CURVES AND THE RECOGNITION OF ADJUSTMENT TO DEPOSITIONAL ENVIRONMENT[1]

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ABSTRACT

The inadequacies of existing methods of obtaining true Gaussian curves are noted and a revised method introduced. Most sedimentary deposits of the grain size range 0–4ϕ are found to obey a logarithmic probability function. The interpretation of the resulting component lines is discussed and two examples are given of the application of this method to the recognition of adjustment of present-day and past deposits to their depositional environment and subsequent addition of material.

INTRODUCTION

Incomplete reworking of earlier deposits may occur where there are variations in air or water currents under natural conditions (Doeglas, 1946). In these cases, the mechanical composition may not be fully adjusted to either the depositional or erosional environment.

The recognition of these mixed deposits is extremely difficult using existing methods unless the constituent materials are markedly different and easily identifiable. In most of the earlier studies of the mechanical composition of present-day sediments (for example, Udden, 1898, 1914; Wentworth, 1931), workers have assumed that the deposits are fully adjusted to their depositional environment. This is rather a dangerous assumption. An entirely wrong impression could be obtained as to the nature of typical adjusted material by studying material unadjusted to a given environment. Since the work of McKelvey (1940) many workers have tried to overcome this by taking large numbers of samples, especially when dealing with marine sediments. However, there is still no absolute proof that all or any of the samples are adjusted to their depositional environment.

The use of cumulative curves, considered as combinations of Gaussian or Log-Gaussian distributions (hereafter they are called "Gaussian curves"), provides an effective way of handling these problems. The correct probability curve splits any multicomponent curves into their fundamental parts as far as possible within the obvious limitations of sampling errors. Thus a single component curve becomes a straight line when plotted on the correct probability scale.

Any statistical system is appropriate for describing sediments, but care must be taken in the selection of the system if one wishes to use statistics in interpreting the data. The "equivalent grade" and "grading factor" of Baker (1920, p. 415) overcame the difficulty of possible multicomponent curves by being based on the slope and shape of the entire cumulative curve. Every change in any part of the curve is therefore reflected in these two parameters. The other statistical parameters most frequently used (Trask, 1932; Inman, 1952) are only really useful in describing the shape of a given curve if the cumulative curves consist of only one component part. Any changes in any small part of the curve such as may occur in multi-component curves are at best inadequately expressed in the resultant parameters. Considerable errors may arise if one tries to work back to the original cumulative curve. Unless tables are also given (that is, according to Udden's tabular system) only very limited work can subsequently be done with the data. This has resulted in considerable loss in value of the work of most subsequent American scientists according to Doeglas (1946). It stems from the use of a few parameters based on a few arbitrarily chosen points on the cumulative curve.

After Hatch and Choate (1929) had noted that particulate material generally obeys a logarithmic probability law, Krumbein (1938) suggested that clastic sediments might do likewise. Thence commenced the investigations into the possible Gaussian

[1] Based on part of a thesis for the degree of Master of Science in the University of London. Manuscript received October 14, 1957.

curve distribution of clastic grains in sediments (summarised in Pettijohn, 1949, p. 34–39). There was a considerable diversity of opinion as to which probability curve is obeyed by many clastic sediments (see below). These doubts remain unanswered.

A THEORETICAL APPROACH TO THE NUMBER OF POSSIBLE COMPONENT CURVES

In a study of the windblown deposits in the aeolian microenvironments of the Suez Canal Zone, Harris (1957) found definite modifications of the grading of the dune sand material depending on the physics of the processes involved and the nature of the geographical environment. These modifications were found to agree with a deduction from Bagnold's Theory of Saltation, allowing for the effects of grain size variation of the material involved. These modifications should also be closely related to the various component lines found using probability paper. Thus, theoretically, five straight lines might be expected to occur:—

1.—Corresponding to the finest grades present and therefore subject to total suspension when the wind is at its strongest, but otherwise moved by saltation.

2.—Corresponding to the finer interstitial material, and consisting of a moderate amount of material of a fairly wide grading range.

3.—Corresponding to the bulk of the deposit, yet of a narrow grade range.

4.—Corresponding to a few large grains raised by saltation only by the strongest winds, while otherwise this fraction would move entirely by surface creep.

5.—Corresponding to large grains moved wholly by surface creep. It will therefore have a greater range of grading and consist of a higher percentage of material present than in the first case.

Doeglas (1946) showed that complications arise where mixing of material or reworking of a sediment occurs. Mixing of material results in an "S" shaped curve with the percentage of material being that corresponding to the flattest part of the "S". The extreme ranges for the materials mixed together can also be determined. Reworking of material or partial deposition of the load in a river results in curves at one or both ends of the cumulative curve (the "R" and "T" curves). These curves were actually demonstrated.

Thus the possibility of multicomponent curves in any given environment cannot be disregarded.

PAST METHODS OF PLOTTING PROBABILITY CURVES

The method of plotting the results to obtain a Gaussian curve was described by Otto (1939). The values obtained by sieving or elutriation are plotted graphically on the chosen scale and smooth lines drawn through the points.

This immediately raises difficulties. There are at least 5 component lines possible in theory, and so about 15 points are the minimum for satisfactory accuracy although the degree of accuracy varies with grading range and degree of sorting. In the case of sieve analysis, unless so many sieves are used that mechanical analysis takes prohibitively long, not enough points can be obtained to test adequately whether a given set of results obey a given law. Much will clearly depend on the straightness of the lines and the grading range. Even employing elutriation, there is a limit to the number of determinations which can be made.

If the curve resulting from plotting the results according to the Otto method is accurately transferred to a usual cumulative curve, it is usually found to be sinuous. Figure 1 shows the resulting sinuous curves for samples 4 and 37, while the corresponding cumulative curves will be found in Harris, 1957, figure 1. They differ appreciably, this difference not merely being caused by the limitations of accuracy in transferring a curve from one scale to another. Either the usual cumulative curve or the transferred Log-Gaussian curve may be correct, but not both. The normal cumulative curve is always smooth when a logarithmic grading scale and arithmetic percentage scale is used. This smoothness remains even after doubling the number of sieves used.

It would therefore seem more reasonable to accept the usual cumulative curves as being the better method of showing grain size distribution.

Other difficulties arise through the scale involved. Certain functions, including the arithmetic scale, require far greater accuracy in certain grades (and consequently closer spacing of the sieve apertures) than is usually necessary in a cumulative curve

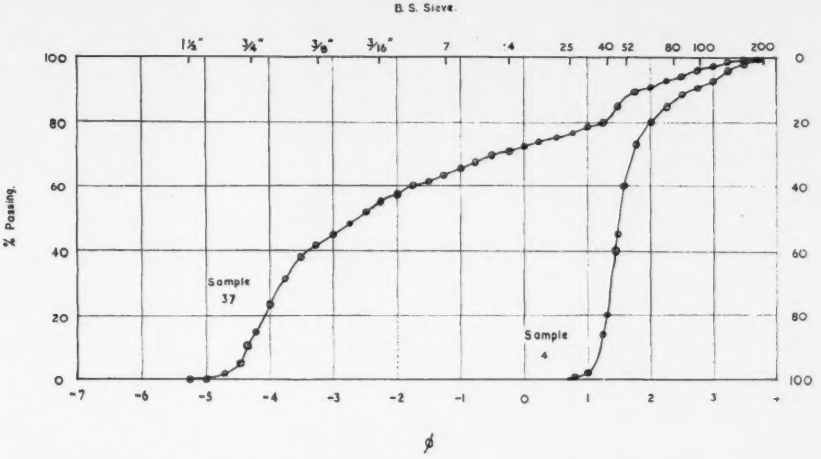

FIG. 1.—Results of transferring the curves of two samples obtained by plotting the results directly on logarithmic probability paper (Otto, 1939), accurately onto a normal cumulative diagram. The points used in transference are shown as circles.

when plotted using existing methods (Doeglas, 1946; Otto, 1939).

Thus there are considerable difficulties in applying the existing methods to sediments. This is particularly acute when dealing with well-graded unconsolidated deposits of sand grade, since only sieve analysis or a time-consuming modification of a microscopic method can be used. The crux of the problem appears to be the need to obtain a more satisfactory mathematical or graphical method of obtaining the Gaussian curve than those discussed above, without adding greatly to the time required for each analysis

REVISED METHOD

If adequate precautions are taken in sampling and sieving and enough sieves are used, an accurate cumulative curve will be obtained which can be transferred to any other graphical scale. The number of determinations per sample required to give sufficient accuracy will depend on the range of grain size present and the degree of sorting. Nevertheless, the number will be considerably less than the number of determinations required to plot directly on to probability paper.

This offers us an alternative method since the cumulative and Gaussian curve should be identical within the bounds of normal plotting errors, apart from being plotted on different scales. Thus, given sufficient care, the cumulative curve can be transferred to any required scale. Quarter-phi units (Krumbein, 1936) are usually ideal in the cases of most deposits. If the original results of mechanical analysis are given, readers can decide for themselves whether any noticeable loss of accuracy may have accrued during the process. Such results are then available for use with any other system a subsequent worker may wish to apply.

In figure 2 the orthodox and revised methods (B and A, respectively) have been used in obtaining the Gaussian curves for two samples from the Suez Canal Zone. Sample No. 37 is of wadi gravel while Sample No. 4 is typical of the local dune sands. In B, both samples give curves which would normally be interpreted as proving that the deposits do not obey a logarithmic probability function. However, using the revised method, the dune sand sample (4) produces four component curves, while the wadi gravel sample appears to consist of two terminal curves (the "T" and "R" curves of Doeglas, 1946) and six component curves with an S-shaped curve in the middle. Thus the samples would appear to obey a logarithmic probability law.

The writer has obtained similar results

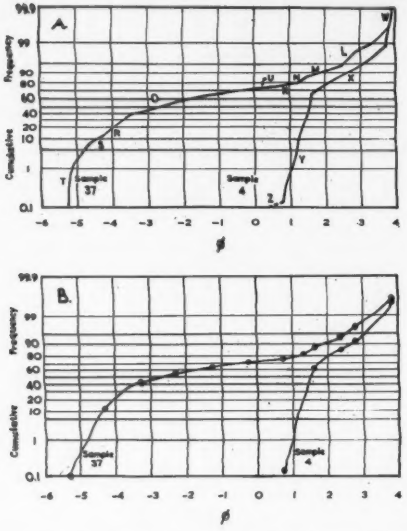

FIG. 2.—Results of plotting two samples on logarithmic probability paper using A, the revised method, and B, the orthodox method (Otto, 1939).

with coarse-textured deltaic, fluviatile, and marine deposits. Wadi gravels are the only deposits with more than four component curves (excluding terminal curves) unless local mixing prior to, during, or after deposition has occurred. In wadi gravels from the Suez Canal Zone, a mixture of finer and coarser fractions is found, each fraction consisting of the usual three or four component curves as in other sediments. No sorting during transport appears to have taken place. This might prove a diagnostic difference between river and wadi gravels unless the mixing is caused by subsequent addition of wind-blown sand to the gravel.

It is this general complexity of the Gaussian curves which has made it impossible to obtain as near a complete breakdown as possible into the component curves using the orthodox method of Otto.

INTERPRETATION OF PROBABILITY CURVES

The general lack of entirely satisfactory results on probability paper has led to a general caution over the interpretation of these curves. Some authors have used the term "skewness" for a method of measuring the degree of departure of the probability curve from a single straight line (plotted using the orthodox method). It has been found to show certain relationships with environment (for example Hough, 1942), so that it can hardly be dismissed as a measure of the sampling error showing up in the tails of the distribution.

Doeglas (1946) demonstrated the method of interpreting terminal and "S"-shaped curves. If a deposit is fully adjusted to its depositional environment, the use of the probability paper obeyed by the mechanical composition of the material will produce a straight line or series of straight lines. Each of these lines will correspond to a particular factor or group of factors in the physical environment.

In order to facilitate description of the Gaussian curves, it is suggested that a letter of the alphabet should be affixed to each component line. Owing to the number of lines which may be involved, the "T," "R," and "S" curves of Doeglas are better referred to as "terminal curves" and "S-shaped" curves. Where convenient, these may be given letters (as curve T, sample 37, fig. 2B), but the number of component curves in a figure frequently forbids this. The letters A–D, P and Q have been reserved for the theoretical lines as discussed in the next paragraph. Letters W–Z are normally used as the counterparts of the

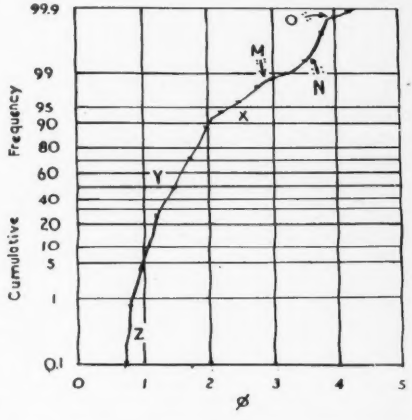

FIG. 3.—Sample 168 plotted on logarithmic probability paper using the revised method.

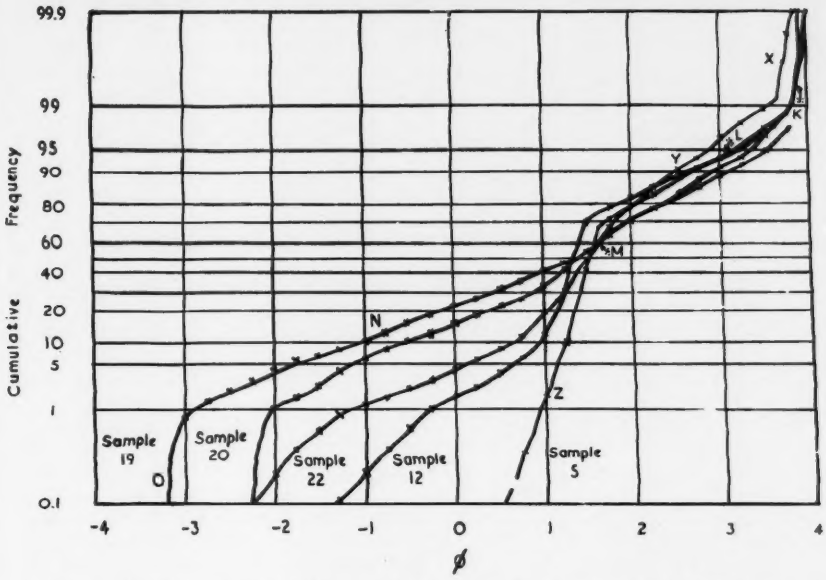

FIG. 4.—Gaussian curves for the five samples demonstrating the stages in wind erosion at Moascar, Suez Canal Zone.

theoretical lines A–D, W corresponding to A, X to B, etc. (Harris, 1955, p. 38).

Of the five theoretical lines described above, four have been found in practice and will be referred to as A, B, C and D respectively. No component curve has been found corresponding to the fourth theoretical line. Any of the four lines may vary, while available material from another source will result in curves as well as straight lines. These lines appear to apply to deposits formed in both aeolian and aqueous environments, suggesting that similar processes are involved. Limited available grades are shown by terminal curves for lines A and D, or both. So far, the writer has not found a line corresponding to the theoretical fourth line in any deposit from any environment. Lines P and Q are reserved for the second pair of lines, B and C, which appear to be found in cases where a secondary mode is formed during attrition (Marshall, 1929).

Failure to yield any straight lines indicates either non-adjustment to the depositional environment, inadequate precautions in sampling, or else that the wrong probability function is being used. This emphasises the importance of determining the function obeyed by each kind of deposit. The presence of finer graded material which has been washed into a coarser textured deposit will be shown by an "S"-shaped curve in the middle of the finest component line (fig. 3). Thus the presence of "skewness" bearing a definite relationship to environment, could be due to mixing of parent material, lack of adjustment to depositional environment, or to the presence of more than one component curve.

Since the percentage scale on probability paper varies, it is impossible to visually compare the relative ranges and degree of sorting of the various components. However, this can easily be overcome by noting the total grading and the actual grade range (in phi units) of each line, together with the respective percentages for a given sample. By dividing the value for the percentage by that for the total grading range (in ϕ units) a convenient value for the degree of sorting will be obtained, which will be called ρ. A high value for ρ indicates a high degree of sorting for the particular component curve. Thus the values for sample 4 are:

Sample 4

Component Curve	Grading Range (ϕ)	Total Grading (ϕ)	%	$\rho = \%/\phi$
W	3.90 to 3.76	0.14	1.5	10.71
X	3.76 to 1.62	2.14	30.3	14.16
Y	1.62 to 0.70	0.92	68.0	73.91
Z	0.70 to 0.23	0.93	0.2	0.15

The equivalent grade can also be used, for instance by plotting it against total range of grades or by plotting graphically the range coarser and finer than the logarithmic equivalent grade. Since deposits of the type under consideration obey logarithmic functions, this is probably of more value than Baker's equivalent grade. It is especially convenient for comparing curves of different phi ranges.

EXAMPLES OF THE USE OF GAUSSIAN CURVES

Wind Erosion of Deltaic Sand

Harris (1957) described an example of wind erosion of Pliocene deltaic sands from the Suez Canal Zone. There appeared to be a continuous change from deltaic sand to the normal dune sand usually found in the area.

Figure 4 shows the results of transferring the cumulative curves to logarithmic probability paper for the five samples showing the stages in erosion at Moascar (see also fig. 3, Harris, 1957). Sample 19 (the undisturbed deltaic sand) shows perfect adjustment to its depositional environment as does sample 5 (the typical dune sand). The other samples show successive stages in the readjustment to the new envirionment, but no straight lines. The data for samples 19 and 5 are as follows:

Sample 19

Component Curve	Grading Range (ϕ)	Total Grading (ϕ)	%	$\rho = \%/\phi$
K	4.15 to 3.50	0.65	4.0	Terminal curve
L	3.50 to 2.00	1.50	18.0	12.00
M	2.00 to 1.40	0.60	28.0	46.60
N	1.40 to −2.50	3.90	47.5	12.18
O	−2.50 to −3.23	0.73	2.5	Terminal curve

Sample 5

X	3.88 to 3.64	0.24	0.9	3.75
Y	3.64 to 1.62	1.02	32.0	15.84
Z	1.62 to 0.50	1.12	67.1	59.91

It is interesting to note the two terminal curves of the deltaic material. These correspond to the loss of the finest material carried away in suspension after deposition, and to the deposition of the coarsest grades carried by surface creep prior to the final deposition of the material (Doeglas, 1946). The lines present correspond to lines B, C, and D of the theoretical curve for deposits transported by fluids, line A being replaced by the finer terminal curve. Thus, this type of deposit obeys a logarithmic probability function, although the detailed proportions of the constituent lines differ considerably from those of aeolian deposits.

Sample 5 yields a typical aeolian curve in which no surface creep is occurring. Thus, the three lines present correspond to the theoretical lines A, B, and C. There is a negligible quantity of material, if any, corresponding to line D.

Similar results are obtained from other areas where wind erosion of deltaic sand is occurring, for example, North Camp. This demonstrates the use of logarithmic probability paper in proving whether or not a given sample is fully adjusted to its depositional environment. Its value can be shown by the following study of the data.

All the curves for the samples of dune sand from this area were plotted on logarithmic probability paper. Sample 77 was found to be borderline between the two groups. In addition, three of the adjusted samples (13, 77, and 78) were found to be of mixed origin.

There is an enormous amount of variation in the component lines of the adjusted samples, and it would seem useless as a secondary characteristic in this case. In addition, ordinary statistical methods would fail to give a satisfactory description of the detailed shape of the curves.

The medians and logarithmic equivalent grades for all the samples have been plotted against one another graphically in figure 5. On this graph, lines have been drawn connecting the series of samples from the Moascar area that were studied separately in the previous paper.

The fields of the adjusted dune sands and the deltaic sand are quite different and distinct while the intermediate material chiefly occupies the space in between. In the deltaic sand, the median is usually greater than the Log. E.G., while in true dune sands, the opposite is the case. Taking the series of five

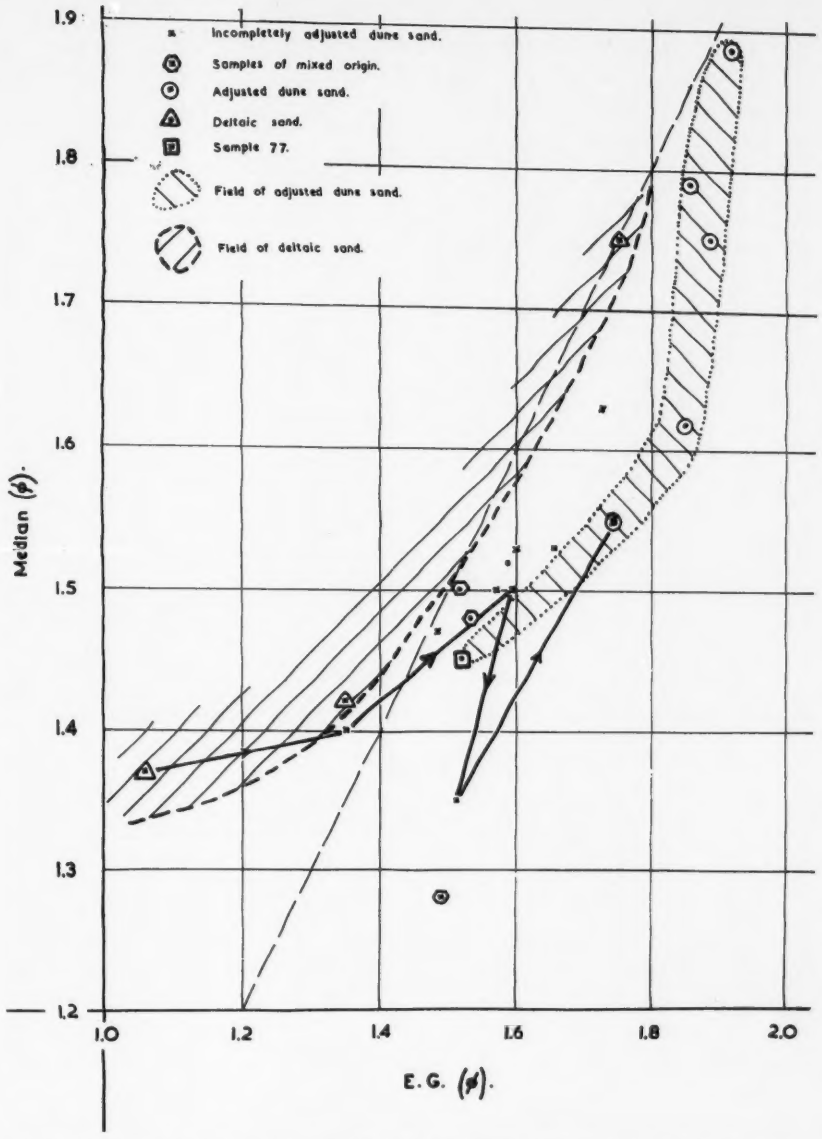

FIG. 5.—Result of plotting median against logarithmic equivalent grade for the samples from the area of wind erosion, Suez Canal Zone.

samples, the three stages are characterised by:

1.—A slight increase in median and a marked yet steady decrease in Logarithmic E.G.

2.—A sudden slight coarsening of the Logarithmic E.G. and a marked change in median in the same direction.

3.—A steady and fairly equal decrease in both median and Logarithmic E.G. showing the effects of the reduction in grain size.

The effect found in the second stage explains the few samples of intermediate material which were found to lie inside one of the two fields.

The dog-legged form of the field of the adjusted dune sand should be noted. The small leg (Log. E.G./Median values of 1.52/1.45 to 1.85/1.62ϕ) possibly represents the sand which is finally completing adjustment to its environment. The main leg (Log. E.G./Median values of 1.85/1.62 to 1.90/1.87ϕ) shows the reduction in median relative to the Logarithmic E.G. during over-all reduction in grain size. This continues until the values for the Log. E.G. and the median are nearly identical.

The results of plotting graphically the ranges of the grades coarser and finer than the Log. E.G. are illustrated in figure 6. Once again, the series of five samples from the Moascar area have been connected by lines and show the stages in the process quite well:

1.—A reduction in the coarser grades while the finer grades decrease only slightly.

2.—A rapid reduction in the finer grades while the coarser grades decrease only slightly. This brings the unadjusted samples into the field of the true dune sands, and is followed by a slight increase in finer grades while the coarser grades continue to decrease.

3.—The finer grades remaining constant while the coarser grades decrease.

Both the deltaic and dune sand fields are well defined but they overlap. The range of

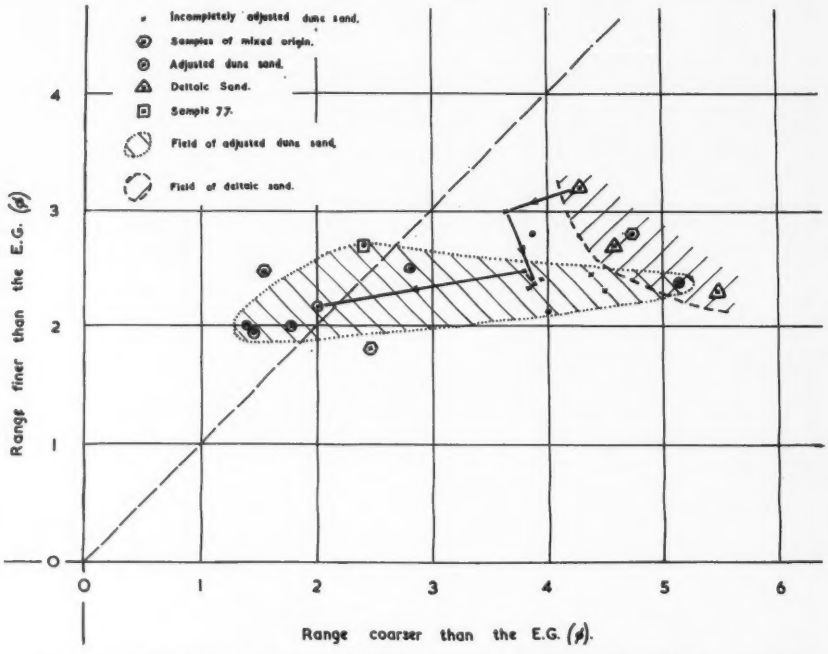

FIG. 6.—Result of plotting the ranges of grades coarser and finer than the Logarithmic equivalent grade for the samples from the area of wind erosion, Suez Canal Zone.

TABLE 1.—*Results of the mechanical analysis of the samples from the Lower Mottled Sandstone at Bridgnorth, Shropshire*

		Sample No.					
		168	169	170	171	172	173
% passing B.S. Sieve No.	3/16″	—	—	—	—	100.0	—
	7	—	—	—	—	99.4	—
	14	—	100.0	—	—	98.9	—
	18	100.0	99.9	100.0	—	98.7	—
	25	99.9	99.4	99.9	100.0	98.5	100.0
	36	99.4	98.2	99.7	99.9	98.1	99.7
	52	60.6	60.7	91.05	89.8	77.6	76.8
	60	11.0	12.4	39.15	42.9	24.6	25.0
	85	3.6	3.0	7.05	10.3	8.4	6.6
	100	2.1	2.2	3.85	6.1	5.7	4.4
	150	0.85	0.8	1.45	1.7	1.9	1.4
	200	0.35	0.3	0.55	0.7	0.7	0.6
	300	0.15	0.2	0.1	0.3	0.2	0.15
Grain Size ϕ	Min.	4.45	4.70	4.35	4.60	4.30	4.50
	Max.	0.46	0.20	0.60	0.76	−2.29	0.76
	Median	1.52	1.53	1.78	1.91	1.64	1.72
	Log.E.G.	1.57	1.57	1.92	1.95	1.65	1.76

Sieve sizes as in Table I, Harris, 1957.
Sample 168: near the top of the upper current bedded unit.
Sample 169: 2 ft below sample 168.
Sample 170: 2 ft below the top of the lower current bedded unit.
Sample 171: 1 ft below the top of the lower current bedded unit.
Sample 172: at the top of the transistion bed (3 in above the base).
Sample 173: at the base of the transition bed (1 in above the base).

finer material in the true dune sand remains constant although the range of coarser material varies from sample to sample.

In each case, stage 1 corresponds to the increase in degree of sorting and the loss of the coarser material. Stage 2 represents the loss of the extra material from the finer extramodal curve following the completion of the loss of the coarsest grades. Stage 3 is due to the final adjustment to the normal dune sand shaped cumulative curve. Thus, this graphical study of the results supports and illustrates the conclusions reached by qualitative study of the samples from Moascar. It also offers a possible new method of approaching the problem of the recognition of environments by study of mechanical composition of sediments. It is proposed to discuss this further in a subsequent paper.

Stratigraphic Section of Lower Mottled Sandstone at Bridgnorth

The section chosen was by the roadside at G.R. 3733, 2959, and just opposite the track leading to Rindleford, Catstree, and Worfield, 2 miles east-north-east of Bridgnorth. It showed about 20 feet of the Bunter Pebble Bed resting on the Lower Mottled Sandstone—a fossil aeolian sandstone (Shotton, 1937).

The Bunter Pebble Bed consisted of a conglomerate at the base with pebbles up to 3 in across, passing up into pebbly sandstone with conglomerate bands. Considerable false bedding and lensing were observed and the direction of true bedding was indeterminable. The bed rested on an uneven surface of Lower Mottled Sandstone, the lower beds exhibiting channelling into the upper surface of the sandstone. On the channel margins, a reworked layer of sand could be seen. This was up to 6 in thick on the steep sides of the channel but died out as it was traced towards the more horizontal top and bottom of the margin of the channel.

The Lower Mottled Sandstone appears at first sight to have parallel bedding with only local lensing. However, careful examination shows that it is actually dipping away behind the section at 20° (strike 196° N.), and probably in the form of at least two current bedded units. The Bunter

Pebble Bed appears to cut across the laminae at a moderate angle from the south-west. Thus this section clearly demonstrates a non-sequence between the dune sand and the overlying beds.

Six samples were collected from the section, two coming from each of the current bedded units and the other two from the reworked layer. Distance vertically below the Bunter Pebble Bed was noted, together with the relative positions in the actual beds.

The results of the mechanical analysis of these samples are given in Table 1, while the corresponding cumulative curves have been plotted in figure 7. Careful examination shows that there is an unusually wide range of finer grades with exceptionally small minimum grain size, while the corresponding cumulative curves are bimodal. Apart from this, the grading follows the typical pattern found in modern deposits (Harris, 1957). The curves group themselves into three pairs, two corresponding to the current bedded units and one to the reworked material. There is practically no variation between the two samples from each current bedded deposit, showing the uniformity of the grading within a given unit. However, a major difference occurs between the material from the top and bottom of the reworked material in that the sample from the top includes a coarser extramodal curve occupying a wide range of grades.

Plotted on logarithmic probability paper, the finest grades show an "S"-shaped curve separating the component lines of a normal aeolian deposit from a finer tail (for example, fig. 3), thus proving mixing at some stage. The point of greatest horizontality gives the percentages of the components of the mixture (Doeglas, 1946). In addition, the points of commencement of the "S"-shaped curve will be the same as the values for those

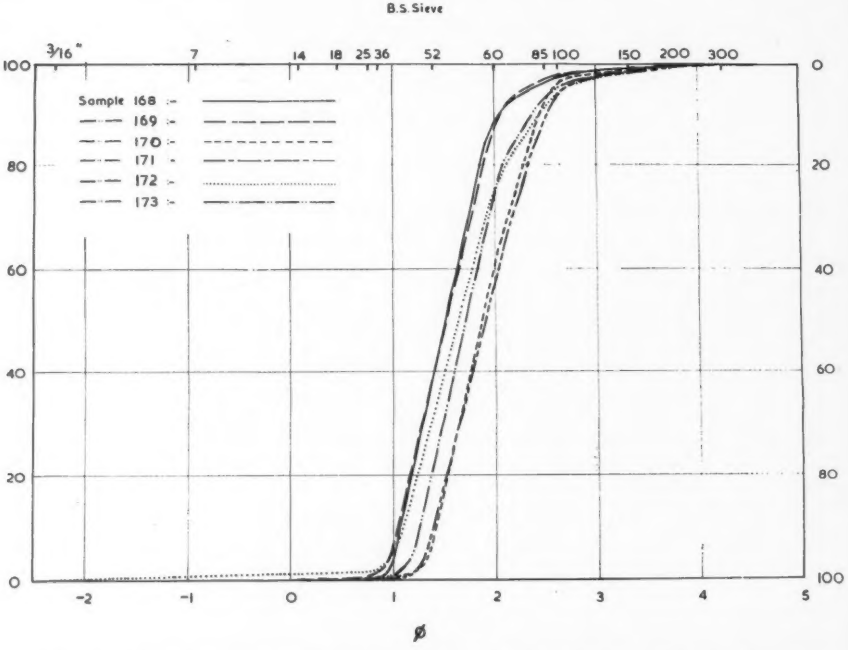

FIG. 7.—Cumulative curves for the samples from the Section in Lower Mottled Standstone, near Bridgnorth, England.

of the distal ends of the component curves of the two parent materials. Thus, points M and N in figure 3 would give the distal limits of grain size of the materials involved. The effect of a line corresponding to the theoretical line A lying totally to the finer side of N will be to produce one or more sharp angles in the finer line as at O. In this case, the point marked by the distal sharp angle instead of N will give the value for the finest material forming the normal curve. In the case of sample 168 in figure 3, it is 3.90ϕ. Thus it is possible to determine the exact amount of material producing the anomaly and the finer limit of grading of the normal curve.

The details showing the anomalies for the six samples, together with distances vertically above or below the Bunter Pebble Bed are as follows:

Sample No.	% Giving the Anomaly (A)	Finest Grade of the Normal Curve (ϕ)	Distance Vertically Above or Below the Bunter Pebble Bed (B)
168	1.2 ± 0.1	3.90 ± 0.02	$-1'6''$
169	0.8 ± 0.1	3.82 ± 0.02	$-2'6''$
170	1.5 ± 0.1	3.45 ± 0.02	$-2'0''$
171	1.9 ± 0.4	3.50 ± 0.04	$-1'0''$
172	2.8 ± 0.1	3.50 ± 0.04	$+ 1''$
173	2.6 ± 0.2	3.20 ± 0.04	$+ 3''$

The values for the corrected minimum grain size of the samples from the lower unit show a lack of the finest grades (3.50–3.80ϕ) normally found in dune sand.

The results of plotting values in column A against the corresponding values in

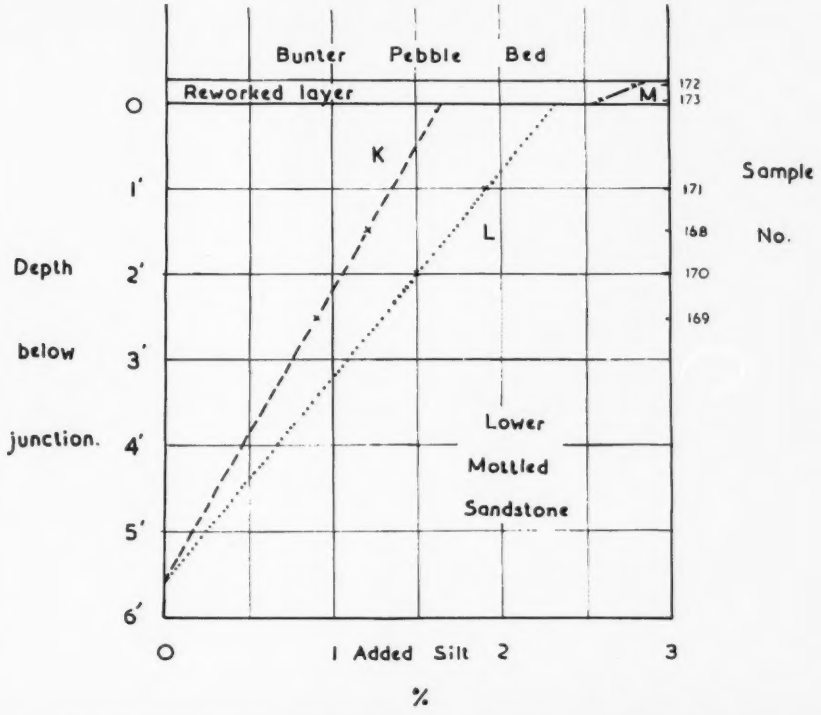

FIG. 8.—Diagram to show the relationship between additional silt and position in the Section in the Lower Mottled Sandstone, near Bridgnorth, England.

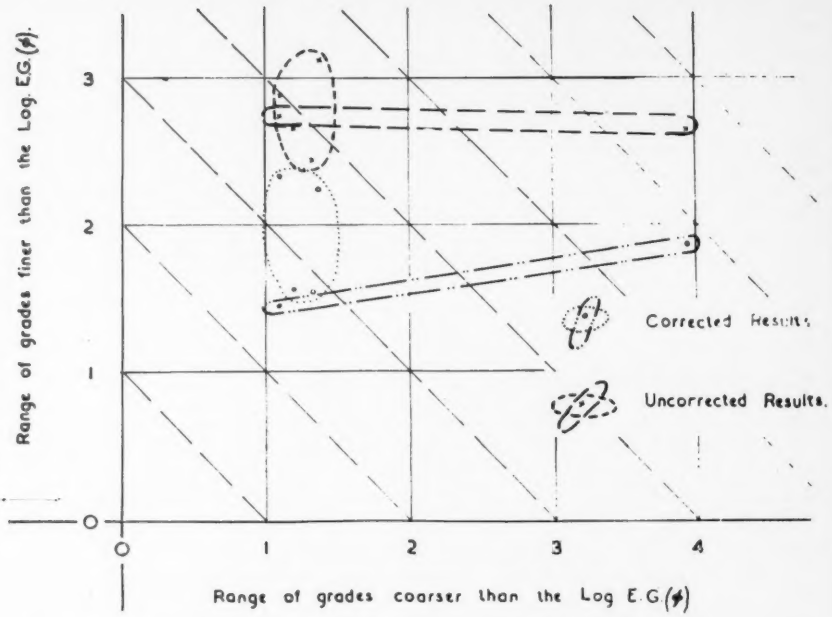

FIG. 9.—Corrected and uncorrected fields for the samples from the Lower Mottled Sandstone, near Bridgnorth, England.

column B are illustrated in figure 8. The pairs of samples from the Lower Mottled Sandstone were collected from directly under the Bunter Pebble Beds where the other current bedding unit did not intervene. Thus in any graphical study of these results, the pairs may be dealt with separately, producing the three lines K, L, and M. K corresponds to the upper current-bedded unit, L to the lower, and M to the reworked deposit. Much higher values for the anomalous material are found in the reworked layer, but these values (and the percentage of coarser grades as noted above) decrease as the time of reworking decreases. Similar decrease occurs in the cases of the lines K and L, but if they are produced to meet the Y axis they intersect at an origin; that is, an identical depth appears to be affected by the anomaly in each unit. The quantity of material added is greater in the case of the finer graded unit which is the opposite of what at first might be expected. In fact, this evidence is consistent with the finest grade of the Bunter Pebble Bed being washed into the top 5′8″ of the underlaying Lower Mottled Sandstone by percolating water penetrating to this depth. A greater quantity would pass through the finer sand and hence the greater amounts of additional material. The greater quantity of fines added to the reworked material supports this conclusion.

With regard to the values of median and logarithmic equivalent grade, these require no adjustment in this case, since any such adjustment would not exceed 0.02ϕ and would be about the same for each of them. The effect of using the correction in comparing, graphically, the range of grades finer and coarser than the Log. E.G. is shown in figure 9. Without using this correction, an entirely different field is obtained which would give the wrong impression if used for quantitative study.

CONCLUSIONS

The need for a method of determining whether a deposit is adjusted to its depositional environment is noted. A brief survey

of existing statistical methods suggest that Gaussian curves might be used. Unfortunately past workers have produced contradictory data, but a careful examination of the method used in the past suggests that the transfer of the cumulative curve to the required scale might prove more satisfactory.

Examples are given of the application of this revised method to deposits from several environments. The interpretation of the resulting lines is discussed. Usually, four component curves are found which can be correlated satisfactorily with a deduction from Bagnold's Theory of Saltation by Harris (1957). The study is confined to sediments wholly coarser than 4ϕ, and they are found to obey a logarithmic probability function.

Two examples of the application of the method are given. In the first case, it is applied to the study of wind erosion of deltaic deposits in the Moascar area, Suez Canal Zone, and enables the stages of readjustment to the new environment to be demonstrated. Finally, the method is used to recognise a case of addition of material to the top of a given bed from the superincumbent horizon by percolating water.

ACKNOWLEDGEMENTS

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FIGS. 1–5, JUNE, 1958

DIFFERENTIATION OF VARIOUS EGYPTIAN AEOLIAN MICRO-ENVIRONMENTS BY MECHANICAL COMPOSITION[1]

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ABSTRACT

A quantitative study of samples from various aeolian microenvironments from the Suez Canal Zone is carried out. The use of the revised method for obtaining Gaussian curves gives further information on their use. All aeolian sands fully adjusted to their depositional environment obey a logarithmic probability law. The sediments of each aeolian microenvironment are found to have different characteristics. Certain failings of earlier morphological classifications are noted.

INTRODUCTION

The writer carried out a purely graphical and descriptive study of samples of dune sand from known depositional environments in the Suez Canal Zone (Harris, 1957). Five microenvironments were recognised. Although a number of characteristics were found to be common to all these aeolian sands, slight differences appeared to be caused by the microenvironments.

Clearly these results, based on a qualitative examination, are worth following up with a quantitative study. However, difficulties arise. How can we be certain that a given sample does not consist of material of two deposits of different grades mixed together? How can we ensure that the grain size distribution of a given sample is fully adjusted to its depositional environment?

Application of a recent revision of the methods of obtaining Gaussian curves to various present-day sediments showed that those of the sand grade appear to follow a logarithmic probability function (Harris, 1958). Cases of mixed deposits and lack of adjustment to depositional environment were examined and it was shown that such deposits could readily be detected by plotting the results of individual mechanical analyses on logarithmic probability paper using the new method. Considerable variation was found when the component curves were examined in detail (table 1). Three or four component curves were usually found corresponding satisfactorily with an earlier deduction from Bagnold's Theory of Saltation (Harris, 1957). The descriptive systems of Trask (1932) and Inman (1952) cannot be applied in these cases since they were designed for single component curves. In an attempt to overcome this, new graphical methods based on the use of the logarithmic equivalent grade (Krumbein and Pettijohn, 1938, p. 256) were introduced. These were applied to the study of aeolian erosion of deltaic deposits between Moascar and Tel El Kebir (see Harris, 1958) and enabled the stages in readjustment of mechanical composition to be demonstrated.

In the following paper, the data from the remaining microenvironments will be examined using the new methods.

RE-EXAMINATION OF THE AEOLIAN MICROENVIRONMENTS

Geographical Environments

In the previous study (Harris, 1957), five microenvironments were examined:

(a) Wind erosion of deltaic sands.
(b) Transport of aeolian sand without further addition of grades.
(c) Aeolian sand on the surface of coalesced wadi fans.
(d) Aeolian sand piled against the Sandy Scarp.
(e) The Bir Themada—'Ain Sukhna pocket of blown sand—a field mill.

All environments apart from (e) include the fullest possible range of available grades. The first case has already been studied in detail (Harris 1958).

Case (b) is an example of an area where sand is moved progressively south and east by the dominantly northerly winds and occasional strong south-westerlies. Initially

[1] Manuscript received January 2, 1958.

TABLE 1.—*Summary of the results of plotting the samples of adjusted dune sand from the area of wind erosion on logarithmic probability paper*

Sample No.	Theoretical Line							
	A				B			
	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$
5	0.28	3.90 to 3.62	0.9	3.21	2.02	3.62 to 1.60	32.1	15.89
72	0.78	4.00 to 3.22	1.1	1.41	0.34	3.22 to 2.88	1.0	2.94
73	0.82	3.90 to 3.08	0.9	1.10	1.18	3.08 to 1.90	16.1	13.64
74	0.15	3.90 to 3.75	0.3	2.00	1.08	3.75 to 2.67	4.7	4.35
75	2.50	4.40 to 2.35	4.5	2.20	1.40	2.35 to 0.95	25.0	17.85
76	0.15	4.30 to 4.15	0.5	3.33	1.75	4.15 to 2.40	19.5	11.14
Range	0.15 to 2.05	4.40 to 2.35	0.3 to 4.5	1.10 to 3.33	0.34 to 2.02	4.15 to 0.95	1.0 to 32.1	2.94 to 17.85

Sample No.	Theoretical Line							
	C				D			
	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$
5	0.38	1.60 to 1.22	53.0	139.47	1.45	1.22 to −0.23	10.0	Terminal Curve
72	1.73	2.88 to 1.15	93.0	53.76	0.69	1.15 to 0.46	4.9	7.10
73	0.78	1.90 to 1.12	76.0	97.44	0.66	1.12 to 0.46	7.0	10.61
74	1.67	2.67 to 1.00	93.0	55.69	0.92	1.00 to 0.08	2.0	2.17
75	1.00	0.95 to −0.05	68.0	68.00	0.88	−0.05 to −0.93	2.5	Terminal Curve
76	2.05	2.40 to 0.35	79.2	38.63	3.58	0.35 to −3.23	0.8	0.22
Range	0.38 to 2.05	2.88 to −0.05	55.0 to 93.0	38.63 to 139.47	0.66 to 3.58	1.22 to −3.23	0.8 to 10.0	0.22 to 10.61

a full range of available grades was present, but no further grades are added from the gravel surface over which it passes. Signs of progressive reduction in grain size with distance travelled were noted.

In the case of (c), the grading of the piles of aeolian sand on the surface of the coalesced wadi fans is controlled by:

1.—The grading of the sand being blown into the areas, which contains the entire range of possible grades.

2.—The available material in the area which is of the right grading for wind transportation by saltation.

The latter is rather coarse and hence the grading of the blown sand appeared to be on the coarse side of that which was found in adjusted dune sand from the area of active wind erosion. Marked coarser extramodal curves were found while a slight increase in the finer extramodal curve also occurred.

The deposits (d) of the Sandy Scarp, Geneifa consist of a covering of sand against a fault scarp, the slope of the sand being less than the maximum possible angle of rest. It is piled there by winds blowing against and along the scarp at an acute angle. The parent material comes from the surface of the coalesced wadi fans, that is, it contains slightly more than the normal range of grades present in dune sands.

A marked variation in grading with height was found, the mean diameter of the sand at the top being half that of the sand at the bottom of the main slope. Even

TABLE 2.—*Summary of the results of plotting the samples from the area of transport without addition of coarser grades on logarithmic probability paper*

Sample No.	Theoretical Line							
	A				B			
	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$
6	0.14	3.90 to 3.76	1.2	8.57	2.24	3.76 to 1.52	38.8	17.32
11	0.65	3.60 to 2.95	3.5	5.38	1.40	2.95 to 1.55	10.0	35.71
80	0.30	3.80 to 3.50	0.8	2.67	1.85	3.50 to 1.65	71.2	38.49
81	0.25	3.90 to 3.65	2.0	8.00	0.90	3.65 to 2.75	12.0	13.33
82	0.85	4.35 to 3.50	1.2	1.39	0.25	3.50 to 3.25	1.5	6.00
83	0.82	4.30 to 3.52	5.0	6.10	1.04	3.52 to 2.48	23.0	22.12
Range	0.14 to 0.85	4.35 to 2.95	0.8 to 5.0	1.39 to 8.57	0.90 to 2.24	3.76 to 1.52	1.5 to 71.2	6.00 to 38.49

Sample No.	Theoretical Line							
	C				D			
	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$
6	0.44	1.52 to 1.08	59.0	134.09	1.31	1.08 to −0.23	1.0	7.63
11	0.30	1.55 to 1.25	45.5	151.67	0.50	1.25 to 0.75	1.0	2.00
80	1.57	1.65 to 0.08	28.0	17.80	—	—	—	—
81	1.05	2.75 to 1.70	81.2	77.33	1.62	1.70 to 0.08	4.8	Terminal Curve
82	2.10	3.25 to 1.15	85.3	40.62	1.07	1.15 to 0.08	12.0	11.21
83	1.63	2.48 to 0.85	69.5	42.6	0.77	0.85 to 0.08	2.5	3.25
Range	0.30 to 2.10	3.25 to 0.08	28.0 to 85.3	17.80 to 151.67	0.50 to 1.62	1.70 to −0.23	1.0 to 12.0	2.00 to 11.21

coarser material was found at the very base of the slope, but this was not quite as well graded as most of the other dune sand deposits from the region.

In addition, one sample (27) of the "funnelling" deposit of Bagnold (1941, p. 191–2) was investigated. Limestone fragments were present, and doubt was expressed as to whether it was a true aeolian deposit. It showed much poorer grading. This will be reflected in the behaviour of the cumulative curves plotted on logarithmic probability paper, since wadi gravels are mixed deposits and might be expected to show mixing in the samples from their upper courses, depending on the parent materials (Harris, 1958, sample 37, fig. 3). A transition zone would be expected to occur corresponding to a mixture following no particular function, as opposed to the material totally of aeolian origin which follows a logarithmic function.

Unlike the other cases, the Bir Themada —'Ain Sukhna pocket of blown sand is a closed system. The locally prevailing winds blow from three opposing directions, confining the pocket of sand to a small area, in spite of considerable, almost daily movement of sand. It is supplied by wind erosion of the nearby beach while blown sand containing all possible grades enters from the south-west. There is probably a continual interchange of a limited amount of material with the beach.

The sand was exceptionally fine-grained and bimodal. No finer extramodal curve was

TABLE 3.—*Summary of the results of plotting the samples from the surface of the Wadi fans on logarithmic probability paper*

Sample No.	Theoretical Line							
	A				B			
	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$
3	0.20	3.95 to 3.75	2.5	12.50	2.15	3.75 to 1.60	51.0	23.72
4	0.14	3.90 to 3.76	1.5	10.71	2.14	3.76 to 1.62	30.3	14.16
7	0.26	3.90 to 3.64	1.0	3.80	2.13	3.64 to 1.51	39.0	18.31
8	1.10	3.80 to 2.70	5.2	4.73	1.12	2.70 to 1.58	19.0	17.00
84	0.85	4.35 to 3.50	1.0	1.18	0.75	3.50 to 2.75	5.2	6.93
Range	0.14 to 1.10	4.35 to 2.70	1.0 to 5.2	1.18 to 12.50	0.75 to 2.15	3.76 to 1.51	5.2 to 51.0	6.93 to 23.72

Sample No.	Theoretical Line							
	A				B			
	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$
3	0.53	1.60 to 1.07	43.0	81.13	2.30	1.07 to −1.23	3.5	Terminal Curve
4	0.92	1.62 to 0.70	68.0	73.91	0.93	0.70 to −0.23	0.2	0.22
7	0.38	1.51 to 1.13	57.6	151.58	1.36	1.13 to −0.23	2.4	Terminal Curve
8	0.60	1.58 to 0.98	69.4	115.67	1.21	0.98 to −0.23	6.4	5.29
84	1.71	2.75 to 1.04	67.8	39.65	4.27	1.04 to −3.23	26.0	Terminal Curve
Range	0.53 to 1.71	2.75 to 0.70	43.0 to 69.4	39.65 to 151.78	0.93 to 4.27	1.13 to −3.23	0.2 to 26.0	0.22 to 5.29 or Terminal Curve

discernible, while the coarser extramodal curve is extremely small.

There are two possible origins of the bimodal nature of the curves:

1.—It might be due to mixing of beach material with finer grained sand from the field "mill."

2.—It might correspond to one of the later stages in abrasion, as demonstrated in laboratory mill experiments, (Marshall, 1929, for example).

Which of these, if any, applies in the cases of the samples collected should be shown by the shape of the probability curves.

Adjustment to Depositional Environment

All the results from the mechanical analyses were plotted on logarithmic probability paper using the revised method (Harris, 1958).

The samples from cases (b) and (c) showed complete adjustment to depositional environment, the important data being summarised in tables 2 and 3 respectively. Comparing these with table 1, it is found that for theoretical line:

A.—The total grading showed a much greater range in table 1, probably corresponding to the incomplete reduction in the area of wind erosion. The percentage of

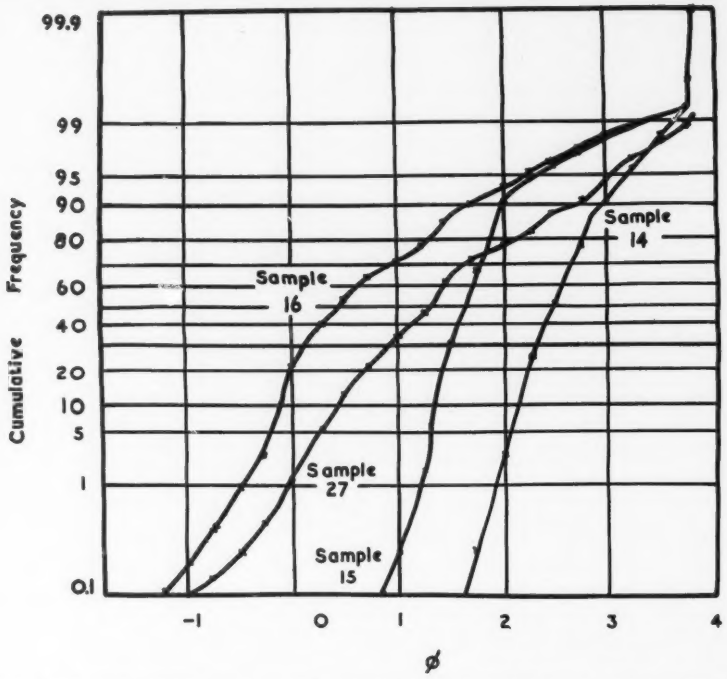

FIG. 1.—The mechanical composition of the samples from the Sandy Scarp, Geneifa, plotted on logarithmic probability paper (using the revised method).

material present was similar in each case, and hence the value for ρ was lower in table 1.

B.—The total grading showed slight differences, the values being least in table 1 and greatest in table 2. The actual grading range was almost identical in tables 2 and 3 but varied far more widely in table 1. The percentages and values of ρ present varied considerably, showing maximum variation in table 2, while the lowest over-all figures lie in table 1.

C.—The total grading is almost identical in tables 1 and 2. In table 3, the variation is considerably less but the average value is similar to the other tables. Maximum variation in actual grading range is found in table 2 since tables 1 and 3 have coarser minimum grain size and tables 1 and 2 have coarser maximum grain size forming this line. Table 2 again shows the maximum variation in percentage present and in ρ. Table 1 has higher percentages than the others, while table 3 shows far greater consistency. In the case of ρ, table 1 has a lower maximum value, while table 2 has a lower minimum value.

D.—The grading range and total grading varies from case to case, being very great in the cases of tables 1 and 3. In contrast, table 2 shows only a moderate range. The lowest values of total grading are found in table 1 and the highest in table 3, but the actual grading range is similar to table 1. The percentage involved is almost identical in tables 1 and 2, but table 3 shows far more variation, corresponding to the extra coarse material. Terminal curves occur in all three tables but are most common in table 3 and comparatively rare in table 2. Tables 1 and 2 have similar values of $\rho-$ but this is twice that found in table 3.

Thus quantitative evidence is found for:

1.—The incomplete reduction in the area of erosion of the finer grades to that typical of normal blown sand.

2.—The greater over-all variability but lack of extreme coarse grades in the case of

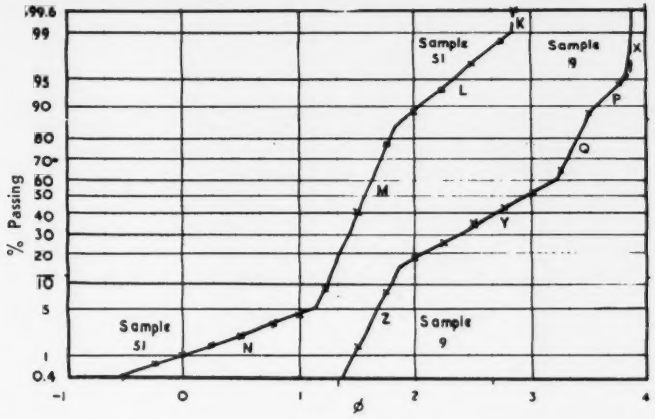

FIG. 2.—The mechanical composition of samples 9 and 51, plotted on logarithmic probability paper (using the revised method).

transport without further addition of local material. Only extremely limited transport by surface creep occurs.

3.—The presence of marked but variable quantitities of material moved by surface creep in the area of dune sand on the surface of the coalesced wadi fans.

4.—The smaller amounts of coarser material moved by surface creep persisting in the adjusted sands in the area of wind erosion.

The results for the four samples from the Sandy Scarp are shown in figure 1. Sample 14 from the crest of the pile shows three straight lines corresponding to those found in the previous cases, less that corresponding to material moved by surface creep. It is fully adjusted to its depositional environment. However, progressive blurring occurs in the other samples, corresponding to either the effects of the commencement of water transport in addition to wind transport (as in sample 27) or to incomplete adjustment to the new and unusual conditions of sorting and deposition (samples 15 and 16).

The results for sample 9 (aeolian sand) and sample 51 (beach sand) from case (e) are shown in figure 2. Sample 19 gave a curve which is not adjusted to its transporting medium, probably because of mixing of sands of similar grading ranges but different percentages of the grades present. This could be brought about by the mixing of materials which have spent different lengths of time in the dune sand pocket.

The important data are summarised in table 4.

It will be seen that sample 51 shows similar lines to those found in a normal dune deposit but the values of ρ and the percentages corresponding to each line are markedly different. The significance of this will be discussed in a later paper.

As regards sample 9, we have lines X, Y and Z, corresponding to the lines A, B and C of the theoretical curve for normal dune

TABLE 4.—*Summary of the results of plotting the adjusted samples from The Bir Themada shore section on logarithmic probability paper.*

Sample 51

	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$
K	0.10	2.80 to 2.70	1.0	10.00
L	0.88	2.70 to 1.82	14.0	15.90
M	0.70	1.82 to 1.12	80.0	114.29
N	3.41	1.12 to −2.29	5.0	1.47

Sample 9

	Total Grading (ϕ)	Grading Range (ϕ)	%	$\rho = \%/\phi$
X (A)	0.05	3.85 to 3.80	4.5	90.00
P	0.32	3.80 to 3.48	7.5	23.44
Q	0.25	3.48 to 3.23	28.0	112.00
Y (B)	1.35	3.23 to 1.88	44.0	32.60
Z (C)	1.13	1.88 to 0.75	16.0	14.20

sands. No material moved by surface creep is present, although it would have occurred in the parent material brought in from the north and the south-west. Lines P and Q are new and show the effect of the second mode already noted, P corresponding to a secondary B, and Q to a secondary C line. The absence of an S-shaped curve implies that the secondary modal curve is due to abrasion and not merely to mixing of sands from different environments.

Relation of Median and Logarithmic Equivalent Grade

In order to show graphically the presence and variation of coarser and finer extra-modal curves in each environment, the median and logarithmic equivalent grade for each sample have been plotted against one another, the fields for the microenvironment being shown in figure 3. Since the modal curves of the samples are fairly parallel (Harris, 1957, figure 5), the median will reflect the relative position of these curves in any two samples. The logarithmic equivalent grade, however, will reflect every difference in shape of the curve.

The samples from the area of transport without addition of grades occupy a long narrow field stretching from a Log. E.G./median ϕ value of 1.77/1.50 to about 1.98/1.95 and then keeping fairly parallel

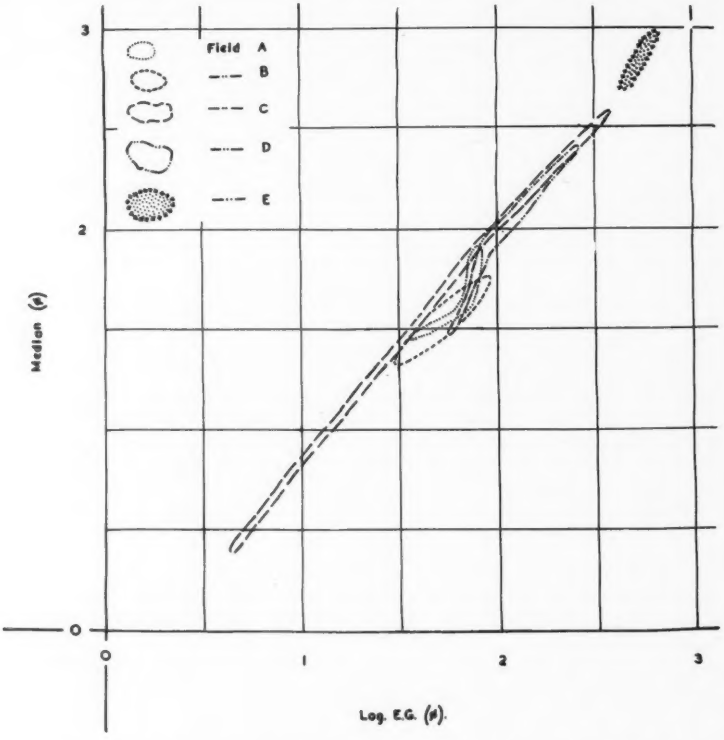

FIG. 3.—The relation of median to logarithmic equivalent grade for the five aeolian micro-environments

A.—Area of wind erosion.
B.—Dunes on the wadi fans.
C.—Sandy Scarp, Geneifa.
D.—Transport without addition of coarser grades.
E.—Closed system at 'Ain Sukhna.

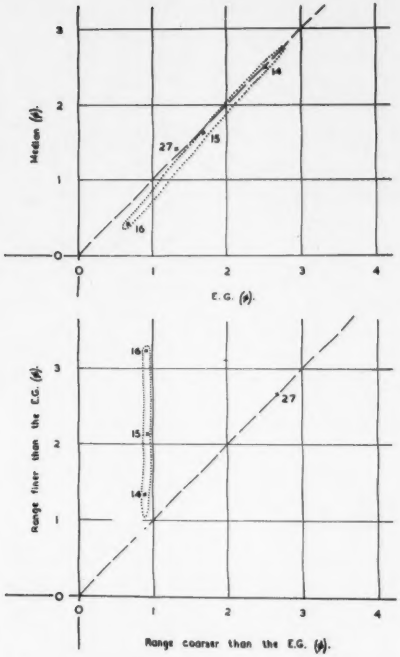

FIG. 4.—The detailed relationship between median and logarithmic equivalent grade, and grain size range coarser and finer than the logarithmic equivalent grade for the samples collected from the Sandy Scarp, Geneifa.

to the line corresponding to Log. E.G. equals median as far as 2.36/2.36 ϕ. (figure 3, field D). This trend parallel to the Log. E.G. equals median line is also seen in other cases, but with considerable modifications. It is a most striking field which is much more extensive than that for fully adjusted samples of the nearby area of erosion (figure 3, field A; Harris, 1958, figure 5). The first part corresponds to and is almost identical with the main part of the adjusted dune sand field from the study of the area of erosion.

The field for the samples from the aeolian deposits on the wadi fans is shown in field B of figure 3. The area occupied by the samples is a long oval field parallel to the line corresponding to Log. E.G. equals Median. It occupies approximately the same position as the shorter leg of field A, but is entirely different to the field found in the case of the associated area of southerly transport without replenishment of the available grades (see field D). Careful examination of the position of the field shows it to be wider than in the case of the area of wind erosion; it extends from Log. E.G./median ϕ values of 1.48/1.35 to 1.96/1.75. This can be correlated with the presence of considerable but varying amounts of additional coarser grades moved by surface creep.

Figure 4 and field C of figure 3 represent the field occupied by the three samples from the Sandy Scarp. The enormous range of grain size is most striking in comparison with other areas. In the case of the coarsest material, the Log. E.G. exceeds the median, but the field trends to the line corresponding to medial equals Log. E.G. and follows it from about 1.70/1.70. Sample 27 lies outside the field on the median side.

The field representing the samples from the Bir Themada pocket of sand lies close to the line corresponding to median equals Log. E.G. (field E of figure 3). The value of the Log. E.G. is slightly less than that for the median and is exceptionally fine.

Comparison of the Ranges of Grades Coarser and Finer Than the Logarithmic Equivalent Grade

The logarithmic equivalent grade is the true "centre of gravity" of the cumulative curve. As such, it does not take into account the actual grading range of a sample; two samples may have the same logarithmic equivalent grade but different grading ranges. By plotting the ranges coarser and finer than the logarithmic grade against one another, a convenient measure of both the over-all grading range and the ranges of coarser and finer textured material than the "centre of gravity" may be obtained.

Figure 5, field D shows the field for the samples from the area of transport without addition of grades. It is interesting to note the extremely small oval field occupied by the samples and the way in which there is practically no variation in the range of the coarser grades and only a little more in the case of the range of finer grades. Once again the field is quite different from that for the fully adjusted samples of an area of erosion (field A of figure 5; Harris, 1958, figure 6).

The field for the samples from the dunes on the gravel fans is similar to that of the

adjusted dune sand from the area of erosion (figure 5 field A). However, it is not absolutely identical, nor would this be expected since the product is not the same, nor is the starting material. In the present case, the range of finer grades becomes slightly greater as the ranges of coarser grades increase, instead of remaining constant. Once again, the field is very long, showing a wide range of coarser grades (1.70–4.90ϕ), in marked contrast to the field for samples typical of sand transport without addition of grades.

Study of the field for the Sandy Scarp samples (figure 4) shows that sample 27 lies on the line corresponding to equal ranges of grain size coarser and finer than the Log, E.G., but at 2.70/2.70—a very great range for dune deposits. On the other hand, the other three samples yield a field of an entirely new pattern, suggesting that some new factor is involved. The field extends for more than 2ϕ units along the vertical axis (that is, range of the finer grades), yet the range of coarser grades remains constant at 0.90ϕ. It is therefore a most distinctive field (figure 5, field C).

Clearly, in spite of the normal tendency for increase of wind velocity with height, sorting into zones parallel with the contours occurs, the coarser grades accumulating at the base of the scarp. This might possibly be caused by shearing sorting noted to occur on agitated inclined planes (Bagnold, 1941, p. 239) or it might be caused by the interaction of gravity slope and wind direction. In the latter case it is envisaged that the combined effects of gravity and slope might impart, on the average, a partial downhill motion to a grain knocked into the air by collision during saltation, since the angle of incidence equals the angle of reflection. The force of the airstream would tend to modify this until it was the same as that of the wind or until it landed, whichever occurred first. The greater the mass of the grain the longer it would take to be fully modified in its direction of travel for a given wind strength, owing to its greater mass and momentum relative to the increase in wind resistance. Thus a wind occurs tending to rise upslope while the larger grains continue to remain downslope. In this case, the angle of slope would be in equilibrium with the wind

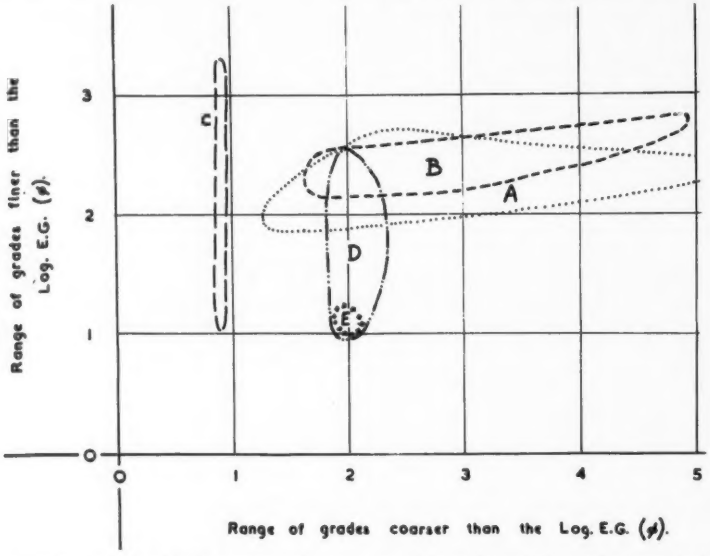

FIG. 5.—The relationship between grades coarser and finer than the logarithmic equivalent grade for the five aeolian microenvironments.

A.—Area of wind erosion.
B.—Dunes on the wadi fans.
C.—Sandy Scarp, Geneifa.
D.—Transport without addition of coarser grades.
E.—Closed system at 'Ain Sukhna.

direction. More observations and possibly some experimental work are required before this problem can finally be solved.

If it was only the position within the sand cloud that altered, then there would be an increase in grain size with height (discussion of Bagnold, 1935, p. 368).

With regard to sample 27, this probably consists of:

1.—Aeolian sand left on the surface of the ground in the lee of the lower ridge and in the re-entrant itself.

2.—Sand washed away from the aeolian sorted material of the Sandy Scarp.

3.—Fragments of limestone eroded from the exposed limestone ridges by the combined agents of wind, flood and diurnal temperature changes.

Of these, the second origin is probably the most important from the point of view of transport and deposition of the deposit. These various materials would become mixed up and transported by sheet flood into the upper courses of the wadis when it rains, thus giving the material its mixed characteristics. Thus this is not a pure aeolian deposit (c.f. the funnelling deposit of Bagnold).

The results for the samples from the Bir Themada—'Ain Sukhna pocket are shown in field E figure 5. In contrast to the previous fields this example shows an unusually small range of grades finer than the Log. E.G. but the range coarser than the Log. E.G. is identical with that of the area showing reduction of grades with distance travelled (another case where decrease in overall grain size is occurring). Samples 9 and 10 do, in fact, just come within the field due to wind transport across an area without addition of grades (figure, 5, field D).

DISCUSSION

An attempt has been made to carry out a detailed study of present-day surface desert dune sediments occurring in a fair sized area. This has provided more evidence as to the nature of the processes occurring during saltation, the use of Gaussian curves and methods of differentiating aeolian microenvironments.

The processes of wind erosion, transport, and deposition under true desert conditions have been examined and the quantitative characteristics of some of the associated deposits determined.

The study of the distribution of the component curves typical of the sediments in given environments can be used to obtain comparative quantitative data. The effect of changes in wind speed during transport and deposition, small variations in slope, and local differences in available grades, appear to be of minor importance. These cause the limited degree of variation found in a given environment, different factors becoming important in different cases; for example, local differences in available grades is probably the main cause of variation in cases of dune sand resting on wadi fans. For the effect to be significant, the cause generally seems to be some marked environmental or physical factor; for example, the presence of coarser available grades or a scarp against which sand is deposited. Only in extreme cases is the modification so sudden and so great as to cause a small area in which lack of adjustment to depositional environment is found, e.g. Sandy Scarp deposit.

The differentiation of the environments is made easier by graphical methods based on the use of the logarithmic equivalent grade. The major environmental factors and changes occurring during erosion and transport can be demonstrated and it provides a simple and easily understandable picture. However, the use of the tabular description is necessary if a detailed quantitative study is required of the changes between the respective component curves. Without the use of logarithmic probability paper detailed quantitative studies would be impossible.

It should be noted that superficially the sandy scarp deposit appears to belong to the wind shadow formation of Hume (1925), but a careful examination of its cause shows that it would be better classified with his scarp-filled drift formation. It does not seem to agree with the group of "sand drifts below cliffs" of Bagnold (1941, p. 192–193). Also, an example of the "funnelling deposits" (p. 191–192) proved to be a deposit of mixed origin. It would seem that classifications based on superficial appearances are of rather limited value to the sedimentary petrologist.

The various aeolian microenvironments found in the Canal Zone have proved to be easily identifiable using the new methods. In every case the full range of possible available grades are present. Each microenviron-

ment had certain definite differences from the others, that is, the secondary characteristics. Certain similarities were also noted. They might therefore form the basis of a new classification of present-day aeolian deposits that can be separated morphologically in the field by physical environment and by mechanical composition.

Two factors must be investigated before this can finally be done. Firstly, the effect of limited available grades must be examined, and secondly, examples of dunes with a thick vegetation cover; for example, many English coastal dunes must be studied. Only when the classification of the aeolian microenvironments has been carried out can the problem of the separation of dune and intertidal sands be adequately dealt with.

CONCLUSIONS

The earlier qualitative results of a study of five aeolian microenvironments from the Suez Canal Zone (Harris, 1957) are followed up by a more detailed study using quantitative methods.

Application of a new method of plotting Gaussian curves shows that all the samples studied obey a logarithmic probability function whenever they are adjusted to deposition environment. This method proves exceptionally valuable in the detection of deposits of mixed origins and of cases of lack of adjustment of mechanical composition to the local conditions of transport and deposition.

The results showed a good correlation with the earlier results, but emphasized the dangers of morphological classification of sandy desert deposits. In the past no attempt has been made to separate the true aeolian deposits from those of mixed origins. The need for a new classification taking account of the mechanical composition, physical environment, and morphology is noted.

Each microenvironment was found to have certain characteristics which are different to all the other microenvironments. These are therefore called "secondary characteristics." Studies of cases of limited available grades and also of the effects of vegetation cover will have to be made before a new classification of aeolian deposits can be drawn up.

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FIGS. 1–2, JUNE, 1958

MEASUREMENT AND ERROR IN REGIONAL STRATIGRAPHIC ANALYSIS[1]

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ABSTRACT

Errors in stratigraphic measurement may be compensating or non-compensating. Compensating errors do not affect the mean value of the attribute under study, but they do inflate the apparent variability of the observational data. Non-compensating errors affect the apparent mean value, and they may distort facies gradients or trends. The more important kinds of error that may enter facies maps are presented in a tabular summary.

The importance of operational definitions in stratigraphic measurement is stressed, and the properties of the resulting numbers are reviewed in terms of the scales of measurement involved. Accuracy and precision, as they apply to stratigraphic data, are touched upon.

A pragmatic method for evaluating facies maps as predicting devices is described. This method takes into account all sources of variability in the original map, including not only errors of measurement and judgment, but the natural large scale and small scale stratigraphic variations as well. An example is used to illustrate the expected average magnitude of the uncertainty in predictions from a specific facies map.

INTRODUCTION

Numerical data, such as thicknesses of strata and related observations, have been used in stratigraphy since its beginnings as a science. The measurements are used as factual data in preparation of stratigraphic sections, for description and correlation of stratigraphic units, and for preparation of isopach and facies maps of the stratigraphic unit.

In addition to their direct use for the preceding purposes, stratigraphic measurements may be considered as representing a sample from all possible similar observations that could be made on the strata in the area of interest. As such, the measurements are statistical observations from which inferences may be drawn regarding the geometry and composition of the three-dimensional body of rock.

As used here, the term quantitative stratigraphic analysis refers to the explicit use of formal methods of analysis in evaluating and interpreting the numerical data of stratigraphy. In large part these methods are statistical, and they involve the estimation of mean values, degrees of variability, associations among stratigraphic variables, and the detection and evaluation of areal variations in stratigraphic aspect. This last is among the more important applications, inasmuch as it involves the analysis and interpretation of isopach and facies maps by formal methods.

Some stratigraphic measurements may be so approximate that they do not justify application of formal numerical methods of analysis. For such, interpretation by conventional methods within the limitations of the data provides at least a qualitative foundation for inferences. When the stratigraphic numbers themselves are relatively reliable, the use of formal methods of analysis may sharpen interpretation of the data in several ways. Average values may be expressed in terms of confidence limits that indicate the degree to which the observed mean value agrees with the "true" mean at some selected level of likelihood. The study of areal variations in maps is facilitated by formal methods inasmuch as quantitative estimates are provided of the gradient components. These may be used to predict quantitatively the most likely value of a stratigraphic attribute that may be encountered in a projected borehole. Such predictions can also be expressed in terms of confidence limits.

Advancement in understanding of sedimentary and other geological processes that affect stratigraphic variation requires examination of the underlying physical and chemical laws that govern the geological processes involved. This is largely an an-

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alytical approach in contrast to the statistical approach. Statistical methods can play a part in such analysis by evaluating the reliability of stratigraphic data, in helping select the more important geological factors that may be involved in a process, and in pointing the way, during early stages of analysis, to some of the more promising lines of analytical attack.

Aside from its contributions to understanding of underlying principles, statistical analysis perhaps plays its most important part in providing a framework for decisions based on stratigraphic knowledge. Facies maps are economically useful to the degree that they permit accurate interpolation of expected values at the site of proposed boreholes, or to the extent that they permit extrapolation of facies trends beyond drilled areas. Such interpolations and extrapolations contain an element of uncertainty, and it is desirable to have some measure of this uncertainty. In choosing a course of action from data provided by a set of maps, knowledge of the relative reliability of the predicted values from the several maps obviously provides a better basis for decision than if all maps are considered equally reliable or equally unreliable.

In order to assess the probable reliability of a prediction before the event, it is necessary to have some knowledge of the variability of the observational data, inasmuch as this variability determines to a large degree the uncertainty involved in any prediction. The problem is complicated by the fact that there is a natural variability in stratigraphic data from point to point over a map area, as well as a variability that may be introduced by actual errors of measurement. Evaluation of the natural variability involves considerable subjective judgment, including assessment of purely local sources of variation (such as sand bars, local structures, and buried hills) in contrast to more widespread regional effects that apply to the whole basin of deposition.

Errors of measurement, in contrast to natural causes of variability, may arise from various sources to be described later, or they may be introduced by errors in stratigraphic correlation due to uncertainty about the upper and lower limits of the stratigraphic unit from well to well. Some of the variability shown on facies maps can in some instances by traced to this source as when unusual or geologically unlikely patterns develop during the compiling stages of a map. Sometimes review of the original correlations shows the source of the variation to be a miscorrelation.

The final test for any method of prediction is to see how well it performs in practice. Facies maps provide many opportunities for such tests in that formal predictions can be made for projected boreholes, and when the data are available (commonly within a year or less) it is possible to see whether the predictions were statistically sound or not. By study of failures particularly, it is possible to sharpen the bases for prediction by modifying the kinds of subjective judgments and the statistical assumptions that of necessity enter the problem of evaluating stratigraphic data.

The present paper is designed as an introduction to the general subject of measurement and error in regional stratigraphic analysis. For this purpose operational procedures used for generating numbers are reviewed, as are some of the common types of error that enter measurement. The discussion emphasizes stratigraphic data of the types commonly used in facies maps. The topic of evaluating actual maps is developed to a first approximation by description of formal methods that may be applied in practical facies map analysis.

OPERATIONAL DEFINITIONS

An operationally defined magnitude is a number that arises when a specified measurement operation is performed on an object under fixed rules. Several criteria of a well-defined operational definition are (1) the number obtained has specific meaning in the subject-matter field, (2) the number is obtained by an objective process, and (3) the number is preferably expressed in a form suitable for convenient mathematical and statistical analysis.

The first criterion emphasizes the need for assessing the physical or geometrical meaning of the number obtained. It is conceivable that an operational definition could be set up to generate numbers that have no readily apparent meaningfulness in a given study. It is the responsibility of the originator of the operational definition to demonstrate that his number has the

meaning he intends. The objective nature of the measuring process is important in eliminating subjective judgments during the measurement. It assures that any qualified person, after some training, is able to obtain essentially the same value for a specific measurement as any other operator.

The third criterion of a satisfactory operational definition refers to the "scale of measurement" used in obtaining the number. When possible, it is advantageous to express the number in such form that any desired mathematical operation may be performed on it. As the next section will indicate, there are limitations in the processing of some kinds of numerical data.

It is not always possible to satisfy all the criteria of good operational definitions in stratigraphic measurement. Part of the problem is related to the difficulty involved in expressing some qualitative concepts numerically. Even the desirability of quantifying some features of stratigraphic analysis may be argued. Cost or time may be controlling factors in some measurement processes, so that approximate methods may be preferred to more exact ways of obtaining the numbers. These situations are developed in later examples.

The specification of objective rules of measurement is perhaps the most important part of an operational definition. In some stratigraphic studies based on electric logs, a common procedure for measuring "net sand" is to measure the cumulated thicknesses over which the SP curve projects beyond a parallel line drawn say 20 millivolts from the shale base. This is an operational definition, relatively free of operator error, but it may not be wholly consistent from log to log owing to varying mud conditions that affect the SP response. In counting the number of sands in a stratigraphic interval an operational definition is virtually imperative if the personal element is to be removed. Forgotson (1954, footnote 3, p. 2485) describes in detail the operational definition he used in counting the sands in the Schuler Formation (Upper Jurassic) of the Gulf Coast area.

Although an operational definition substantially removes the subjective element from a measurement (or at least forces it within bounds), there is no assurance that operational definitions *per se* give error-free values. Thus, in applying any fixed millivolt interval for measuring net sand, a serious error may enter the measurements if the SP quality of the logs changes significantly over the area mapped.

SCALES OF MEASUREMENT

Stevens (1946) defined a measurement as the process of assigning a numerical value to some quality of an object, in accordance with definite rules. The rules are specified in the operational definition, and the resulting numbers have properties that depend in part on the kind of "yardstick" used in making the measurement.

Four kinds of yardsticks or scales of measurement are recognized. The simplest is the nominal scale, used to establish equivalence among objects in terms of some quality that they possess. This is the process of classifying objects. Some would hesitate to apply the term "measurement" to this process, although a number for each class is as appropriate as a name. There may be no necessary relation between the successive numbers, inasmuch as any class may be designated the first class.

When objects are classified according to the relative amount of some quality that they possess, the grouping gives rise to the ordinal scale. This requires that a distinction can be made in the "more than" aspects of the quality. The ordinal scale preserves relative rank, and there is a logical sequence to the numbers assigned to the ranked classes. However, the numbers may not be equally spaced in the sense that each class represents an equal interval on some continuous scale. The Mohs hardness scale is a classic example of an ordinal scale.

The third level of measurement is the interval scale. It requires that an equality of intervals or of differences between successive numbers can be established, but it may have any convenient zero point. The Centigrade temperature scale is an interval scale with an arbitrary zero at the melting point of ice.

The fourth and highest level of measurement is the ratio scale, which requires an absolute zero, and demands that numbers assigned to A and B be in the same ratio as numbers assigned to C and D if the ratio A/B is the same as C/D. The ratio scale is the most versatile of the four scales, and it

permits application of all types of mathematical and statistical procedures.

The properties of the four scales of measurement are summarized in table 1, adapted from Siegel (1957). The examples from stratigraphy and sedimentation in the third column illustrate how some measurements in those fields are related to the several scales. The importance of the measurement scales to stratigraphy is that as new numerical concepts are introduced into the science, it is an advantage when they can be expressed on the ratio scale.

MEASUREMENT IN STRATIGRAPHY

Most measurements in stratigraphy, as they relate to facies mapping, are length measurements, such as thicknesses of strata and the like. Length is a continuous variable measured on the ratio scale. Hence, many stratigraphic numbers carry the advantages of this scale. Moreover, errors of actual measurement are generally minor, inasmuch as electric logs, for example, can usually be measured to the nearest foot or two.

Although the thickness measurements themselves are obtainable without appreciable error, uncertainty may enter stratigraphic measurements owing to lack of sharp definition of the thing being measured. As mentioned, when electric logs exclusively are used to measure sand thickness, error may be introduced by the influence of mud conditions on the SP response. It is probably fair to state that some skepticism associated with the use of numbers in stratigraphy arises not so much from the fact of measurement as from the likelihood that the feature being measured is not precisely what it is thought to be, or that the measurement is made on an interval that has uncertain limits owing to doubtful stratigraphic correlation. Such conditions may introduce errors of unknown magnitude into the measurements, and thus cast doubt on the geological significance of the numbers.

Quantitative stratigraphic analysis depends ultimately upon the certainty with which a stratigraphic unit is defined and identified. Definition of the unit proceeds from formal application of well established principles of stratigraphic correlation. If a stratigraphic unit is thought to be defined in terms of time planes, but actually transgresses time, then any measurements made

TABLE 1.—*Scales of measurement*[1]

Scale	Defining Relations	Examples from Stratigraphy and Sedimentaion	Examples of Appropriate Statistics[2]
Nominal	Equivalence	Classification of sedimentary rocks into two or more classes. In general, any grouping based on presence or absence of certain equivalent properties	Frequency in each class Modal class (class with greatest frequency)
Ordinal	Equivalence Order	Classification of objects in some ranked order, as grains into angular, subround, and round; or classification of sands into tight, moderately porous, and highly porous as expressed on electric logs	The median (the middle-most item in a set of ranked items) Various percentiles, such as two quartiles
Interval	Equivalence Order Ratio of intervals	Observed SP of sand kicks as measured from an arbitrary shale line on an electric log may be an example	The arithmetic mean of a set of values. The standard deviation. The product-moment correlation coefficient
Ratio	Equivalence Order Ratio of intervals Ratio of values	Thickness measurements of sharply defined stratigraphic units. Permeability of sandstone as measured in the laboratory	All the preceding, plus the geometric mean and the coefficient of variation

[1] Adapted with some modifications from Siegel (1957).
[2] The statistical terms are defined in standard statistics texts.

on the miscorrelated sections have an uncertain relationship to the "true" unit that is thought to be under study. On the other hand, when the unit represents a readily recognizable lithosome, or an arbitrary slice of rock, this problem does not arise.

It is evident that a large element of uncertainty may enter a facies study when stratigraphic correlation is doubtful. Some errors of judgment may be compensating, but others are systematic and introduce bias into the numerical data. The correlation of stratigraphic sections and the selection of an interval to be mapped in a given area may be the most time-consuming part of a stratigraphic project. This is justifiably so in view of the dependence of all subsequent stratigraphic measurements and geological judgments on the validity of the correlation.

Fortunately for the purposes of many facies studies, correlation of the stratigraphic unit over the map area is satisfactory, so that total thickness data for an isopach map (or elevation of the top of the unit for a structure map) are subject only to the relatively minor errors of measurement on the electric logs. These tend to be compensating errors.

Measurement of lithologic attributes of the stratigraphic section, such as total sand thickness within the unit, depends upon a double process. First the sand is identified, and then its cumulated thickness is measured. The distinction between sand and not-sand (as on an electric log) is basically a classification, and hence is on the level of the nominal scale. Once the classification is made, the actual measurements are in length units on the ratio scale. If the criteria for sand identification are weak due to mud conditions or other causes, then the resulting thickness measurements are weak, even though they are read to the nearest foot on the electric log.

There are numerous stratigraphic measurements that depend basically on a scheme of lithologic classification, so that thickness measurements assigned to different categories, although precise of themselves, depend ultimately upon how well the basic classification was set up. Such situations emphasize the need for carefully defined operational definitions in stratigraphic measurement.

Errors that depend largely upon classifications at the nominal scale level may over- or underestimate the sand thickness in a series of wells, in which case the errors are non-compensating. In other circumstances the errors of classification may be compensating, as when individual decisions disposing of silty beds may sometimes group them with sand and at other times with shale, in accordance with some fixed or randomized rule. Some of the implications of compensating and non-compensating errors are developed in the following section.

CLASSIFICATION OF MEASUREMENTS ERRORS

Errors of measurement may be classified into several kinds (Wilson, 1952, chapter 9). Non-compensating errors either increase or decrease the observed mean value and hence overestimate or underestimate the true mean value. Compensating errors tend to balance out, so that the mean value is not affected. Lack of calibration of a measuring instrument, instrumental drift, or a tendency on the part of an operator consistently to over- or underestimate particle shape in a visual-comparison method, produce non-compensating errors. In time-rock correlation of a stratigrahic unit from electric logs, there may be a tendency to increase the interval thickness as new sands come into the bottom of a section. If these sands are actually in the underlying older unit, a non-compensating error arises.

Compensating errors occur when individual measurements from item to item vary nonsystematically, so that some readings are too small and others are too large. In the long run such errors tend to balance out. In visual methods of estimating particle roundness an experienced operator will over- or underestimate individual pebbles, but the mean value of 100 such measurements may agree well with instrumental measurement. Visual methods are commonly affected by subjective operator variations, in that some analysts tend consistently to overestimate or underestimate. An individual operator thus may introduce a non-compensating error, but among a group of operators measuring samples assigned in a randomized manner, the net effect may be compensating. Griffiths and Rosenfeld (1954) discuss the sub-

ject of operator variation in sedimentary measurements.

In addition to non-compensating errors that may persist through a series of measurements, some individual errors arise because of outright mistakes on the part of the operator. A number may be wrongly recorded or a percentage may be grossly miscomputed. Such "gross errors" are sporadic, and there is no satisfactory way of eliminating them after the fact unless the steps can be rechecked. In stratigraphic correlation an outright mistake in marking boundaries on a log may give rise to this sort of error.

Another source of error in measurement is the "error of method," which arises from a discrepancy between the definition of the true value being sought and what the measurement process actually yields. If electric logs vary over an area due to mud conditions the operational process of measuring net sand on the 20-millivolt reference line may in the case of a poor quality log be measuring not net sand but some attribute of the mud conditions.

Whether an error of measurement is due to an occasional mistake, to lack of calibration of an instrument, to bias on the part of an operator, or to occasional measurement of the wrong kind of thing, the net effect is non-compensating, so that the mean value of the set of observations is displaced away from the true value. That is, the result is inaccurate to a greater or lesser degree. In contrast, when only compensating errors are present, the observed mean is not displaced from the true mean, and the measurement process is relatively accurate. However, large compensating errors in an approximate measuring process tend to inflate the variability among individual measurements, and hence the measuring process may lack precision. The distinction between the two is one of the degree to which the measurement process discloses the true value (accuracy) as against the degree of reproducibility of the measurements (precision). Cochran and Cox (1950, p. 16) discuss these distinctions.

When non-compensating errors are caused by consistent bias in an instrument or operator, they are commonly called systematic errors as against the compensating type, called random errors. Random errors may be large or small depending on the relative precision of the measuring process, and they constitute the unpredictable positive or negative variations that occur in all measurements, even after the gross errors, errors of method, instrumental errors, and operator errors are eliminated.

It is apparent that any of these several types of error may occur in stratigraphic analysis. When the numerical data are to be used for making quantitative estimates about stratigraphic units, or for making predictions on expected values to be encountered in new subsurface tests, it is important to distinguish between errors that tend to reduce or increase the observed mean by non-compensating effects, as against errors that do not affect the mean, but may seriously inflate the variability of the data. The effect of the latter is that lack of precision makes it more difficult to detect small differences between groups of items by statistical analysis. The introduction of large variabilities into stratigraphic data by approximate measurement processes tends to obscure regional trends and stratigraphic differences between sections.

If it is possible to locate the source of non-compensating errors, a correction factor may be used, as is commonly done in correcting electric log thicknesses for known dip of the rocks. The remaining random errors, after the controllable systematic errors are removed, can generally be reduced only by improving the precision of the measurements.

Precision is sometimes deliberately sacrificed on the basis of the much higher cost of precise data, or on the basis of the time element in the study. Stratigraphic measurement of rock types based on detailed sample logs used in conjunction with mechanical logs undoubtedly supplies more reliable data than when mechanical logs are used alone. However, in some studies the much larger amount of data obtained in a shorter time from mechanical logs affords more geological information than would be had from a few logs more carefully studied. Such advantages may arise in map studies where areal changes are large, so that the greater variability among the rapidly-measured values does not obscure the underlying facies trends.

SOURCES OF ERROR IN FACIES MAPS

In addition to the kinds of errors mentioned earlier, added uncertainty may be introduced into a facies map by the manner in which contours are drawn among the control point values. This is particularly true in areas of sparse control, where facies lines may be drawn in more than one way, resulting in maps that are consistent with the data, yet differ in gradients and trends. Inasmuch as either map may be correct as far as available data extend, the uncertainty of predictions based on the maps is greater than if adequate control were available to reduce alternative ways of contouring.

Insofar as the over-all reliability of a map is concerned, uncertainties due to contouring may be included in the general field of "error" inasmuch as they reduce the over-all reliability of any given map. However, such uncertainties are not unique to facies maps; any contour-type map based on limited data is subject to the same limitations.

At the present stage of facies analysis relatively little is known of the absolute magnitude of errors that may be present in maps. Experience in working with stratigraphic data is usually relied upon to provide an intuitive basis for evaluating the over-all quality of a facies map. Where correlation is known to be satisfactory, where control is reasonably abundant, where structure is relatively uncomplicated, and where adequate well log information is available, the actual errors of measurement are usually considerably smaller than the natural variability in the stratigraphic unit from point to point within the section, as well as from one locality to another in an areal sense. The real problems arise in early stages of development, when correlation may be uncertain, control is widely spaced, and detailed lithologic information is largely lacking. Here the uncertainty may not be as much the result of measurement error as of general vagueness that permits more than one way of interpreting the available data.

It would seem from this discussion that the sources of uncertainty in facies maps are of two general kinds: those that depend mainly upon geological experience and judgment (which are common to all fields of geology), and those due to errors in the more usual sense, where operational definitions or scales of measurement are involved in obtaining lithologic and other stratigraphic data for the maps. The reliability of personal judgment can be assessed at least qualitatively by the "success ratio" over a period of time, and some of the more conventional measurement errors can be isolated and evaluated by experiments designed for the purpose.

Table 2 is presented as a summary of the previous discussion, and it lists some of the main sources of uncertainty in facies maps as a qualitative guide in suggesting possible sources of error that may enter facies studies. Critical examination of stratigraphic procedures sometimes suggests ways for reducing some of the uncertainties in specific map projects.

Statistical methods are available for separating and evaluating some of the errors listed in the table. For simple compensating errors an effective method for increasing precision is to make independent duplicate measurements on attributes subject to such errors. Statistical experiments can be set up to estimate the magnitude of specific kinds of errors. Among these are errors in estimating lithologic components from electric logs, in counting numbers of sands, in estimating porosity from special types of mechanical logs, etc. The effects of different geologists making the same measurements may be included here. Griffiths and Rosenfeld (1953) and Rosenfeld and Griffiths (1954) studied operator effects in grain orientation and particle roundness studies, Krumbein (1953) reported incidentally on an experiment to test operator effect on sand-shale estimates from electric logs, and Griffiths and Rosenfeld (1954) summarized the influence of operator error in general. From such designed experiments it is possible to acquire data on the average magnitude of certain kinds of error that may be anticipated in facies studies.

Separation and evaluation of non-compensating errors, especially those that involve geological judgment rather than application of a fixed operational definition, appears to be a more difficult problem. If two geologists make independent correlations, the mere fact of disagreement may

TABLE 2.—*Sources of error or uncertainty in facies maps*

Source	Remarks
Miscorrelation	"Errors of Judgment." These may be compensating when uncertainty results in picking either too thick or too thin an interval. More commonly, perhaps, they are non-compensating, and may involve a cumulative effect
Lack of Sufficient Control Points	"Error of Judgment." The subjective choice from among alternative ways of contouring a map may introduce incorrect trends or gradients into the map. Effects apparently are generally non-compensating
Incorrect Identification of Lithologic Types	This type of error may arise in mechanical logs, where the initial problem is one of classifying the rocks as type A or not-A. In part, errors of judgment may be involved, although operational definitions are usually indicated. With good quality logs the errors appear to be mainly compensating, but where log quality varies, poor development of the SP curve may introduce systematic errors
Operator Effects	Some workers are liberal and others are conservative in measurement and rounding. Individual differences tend to be systematic. Data prepared by a single geologist are usually consistent. Strict adherence to operational definitions helps reduce operator differences
Errors in Thickness Measurements	Assuming that the category of attribute to the measured is correctly chosen, errors of actual measurement are commonly small and compensating. These errors may rise to importance in very thin stratigraphic units
Counting Errors	Number-of-sands counts are strongly affected by personal judgment unless an agreed-upon operational definition is explicitly followed. The definition itself needs careful statement in terms of the objectives of the map study. Counting errors may be compensating or non-compensating
Computing Errors	Computation of percentages and ratios commonly gives rise to small compensating errors, although systematic rounding errors may occur. Gross errors may occasionally occur

not disclose where the error lies. A qualitative estimate could be made by examining two maps of the same stratigraphic unit correlated by different criteria. Such comparisons sometimes give strong suggestions regarding inconsistencies in one or another of the maps.

Despite the lack of quantitative information on the magnitude of measurement errors that may occur in a map, as well as the unknown magnitude of possible errors of judgment, methods are available for looking into the implications of different kinds of error in facies studies. For example, separation of the original facies map into regional and local components (Krumbein, 1956) offers one way of separating compensating errors from non-compensating errors, even though their magnitude is not known.

Where errors of measurement or of judgment are present in the original map, these errors will be distributed over the regional and local effects maps in the following manner: the compensating errors, from whatever cause, will be included in the local effects map and the non-compensating errors, from whatever source, will be included in the regional map. Hence, even though one may not know whether errors of measurement or of judgment are present or not, he is assured to a first approximation that any systematic errors present are in the regional map, and any random errors are in the local effects map.

The reason for this separation of the errors is that the natural small scale stratigraphic variations in the map area are treated in the same way as random errors by the method of analysis, whereas any errors that affect the observed mean value of the attribute are carried over to the regional map. The information in table 2 can be used to assess some of the kinds of errors that are most likely to modify the regional and local effects maps. Errors of judgment in correlation or in placement of

contour lines, insofar as they are non-compensating, modify the average value of the attribute mapped, and may modify the "true" regional gradients and trends by changing their apparent slopes and directions. Non-compensating operator effects and some errors due to poor quality logs may have similar effects on the regional map. Purely compensating errors, mainly those of actual measurement and computation, increase the apparent variability of the natural small scale variations of the stratigraphic unit in the local effects map.

As far as the writer's experience in map analysis extends, it supports the inference that in most reasonably good facies maps the natural local variations in the stratigraphic unit are much larger than the compensating errors of measurement that may be present. In very thin units, where small absolute errors may be relatively large, some compensating measurement errors on poor quality data may rise in importance. Here the problem may be one of increasing the precision of the observations in some manner.

It is the writer's experience that in regional maps having strong gradients or trends, there need to be relatively serious non-compensating errors in order to distort the gradients sufficiently to produce a wholly erroneous map. Even when errors of correlation are hidden in such maps, they retain a kind of internal consistency as long as the same kinds of correlation errors are made in measurement of new logs. When a new test discloses the error, the map may require extensive modification. In slice maps and lithosome maps these complexities are less important than in maps of stratigraphic units with presumably time-parallel boundaries.

In summary of this section it may be emphasized that serious errors may enter facies maps when control is scarce, or correlation is weak, or data are poor. This is true of any kind of map, and is not unique to facies maps. It seems safe to assert that the majority of broad-scale facies maps, based on reasonably well distributed control points, are not seriously distorted in their over-all qualitative patterns by the kinds of errors that may arise in the everyday experience of professional stratigraphers. This does not imply that possible errors should be ignored; as more quantitative techniques enter facies mapping the need for error evaluation rises in relative importance.

Some situations arise in which the naturally-occurring local stratigraphic variations are so large that the maps have spotty contour patterns. This is true, for example, in sand maps of thin units characterized by bars or other local features. Thin carbonate units may similarly have a spotty distribution of porosity. In such cases lack of predictability is less a function of measurement or judgment error than of insufficient data to bring out minor details in the unit. Such maps are naturally "noisy" as far as underlying trends and gradients are concerned.

PRACTICAL EVALUATION OF FACIES MAPS

It was mentioned that facies maps are economically useful to the degree that they may be used to predict stratigraphic aspects encountered in new borings. A pragmatic method of map evaluation can be developed that takes into account all the sources of variability in the original map. These include the natural large scale and small scale stratigraphic variations in the unit, the errors made in actual measurement, and the more subjective errors that may be involved in correlation and contouring. All of these factors affect the usefulness of the map as a predicting device.

The method is based on separation of the original facies map into its regional and local components. Such separation involves a large subjective element (Krumbein, 1956) in that a decision needs to be made regarding the terms assigned to each component. Once this decision is reached, with the aid of statistical reasoning if desired, the regional map can be made the basis for prediction of the expected value that may be encountered in a new test boring. This is done by computing the value of the regional surface at the proposed drilling point, or by interpolating it between the contours of the computed regional map. The local effects map, in turn, supplies an estimate of the uncertainty in the prediction, because the variability in the local effects map furnishes an estimate of the average magnitude of departures from the regional surface.

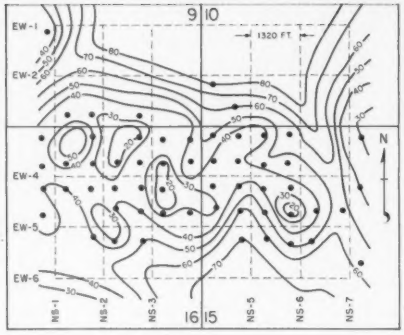

FIG. 1.—Net sand thickness, Reynolds zone, West Brock area, Carter County, Oklahoma. Reproduced from Krumbein, 1956.

An example of this rough evaluation can be drawn from an earlier paper (Krumbein, 1956, fig. 1, p. 2168). The original map is shown reduced in figure 1. From analysis by an abbreviated regression method, the regional and local effects maps of figure 2 were obtained. Analysis of the original data based on interpolated values from figure 1 (listed in table 3, upper left, p. 2191, Krumbein, 1956) showed the total variability of the original map (total sum of squares) to be 15,369.63 (ft^2). The total variability of the regional component was found to be 12,072.59, and the variability of the local effects map (residual component) was the difference between these, equal to 3,297.04. The regional map contained seven polynomial terms, so that the residual sum of squares had $41-7=34$ degrees of freedom. The residual mean square is $3,297.04/34=96.97$, and its square root, representing the estimated standard deviation, is 9.8, rounded off to 10 (ft).

On the assumption that the parent distribution is essentially normal, the residual standard deviation is a measure of the uncertainty in any prediction made on the regional map. For example, from the regional map of figure 2 the computed thickness (expected value) of sand to be encountered in a well drilled in the center of the upper right grid square in figure 1 is 75 ft. The uncertainty in this prediction due to the average value of the local effects is such that there are roughly two chances out of three that the well will encounter $75\pm10=65$ to 85 ft of sand. The relative error here is $10/75=13$ percent. If the prediction is to be based on a 19/20 chance, the confidence band becomes twice as great, from 55 to 95 ft, representing a relative error of about 25 percent in this location.

The "relative error of prediction" varies over the map area when an average variability from the local effects map as a whole is used to express the uncertainty. For example, the predicted thickness of sand to be encountered in the center of the lower left cell of figure 1 is 47 ft. When this is straddled by the average uncertainty, there are two chances out of three that the value will lie in the range $47\pm10=37$ to 57 ft, a relative error of 21 percent at this probability level.

With more complete analysis of the data by methods that do not require interpolation

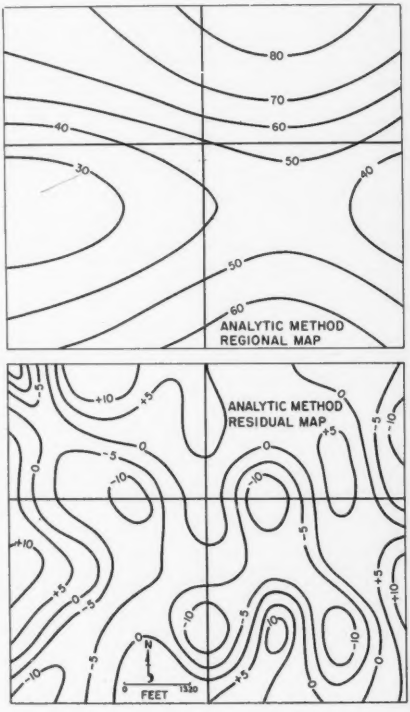

FIG. 2.—Regional and local effects maps of West Brock area obtained by abbreviated regression method. Reproduced from Krumbein, 1956.

on the original map, some of the uncertainty attributable to errors of interpolation can be reduced. The more exact methods are very time-consuming unless a high speed digital computer is available. Additional refinements of method are possible by using the pattern of the local effects map (rather than an average variability based on the whole map) to get at the expected value of the local departures in the vicinity of the proposed well. This can be done by separating the first local effects map into two parts, one of which represents, as far as can be judged, the "true" bars or other features present, and the other of which contains the "noise."

Even without the added refinements of further analysis, the pragmatic method affords a basis for evaluating the over-all usefulness of the map as a predicting device. It is to be emphasized that in the average case the size of the "error of prediction" is not so much a gauge of the quality of work done by the map-maker as it is of the inherent uncertainty in the geological picture due to lack of data in the critical areas.

Comparison of a set of facies maps, showing different aspects of the same stratigraphic unit, provides a rough rule of thumb for ranking the maps on the basis of their usefulness as predictors. Critical examination of the apparently less reliable maps for possible measurement or judgment errors, plus further analysis of the local effects, may commonly increase the efficiency of such maps in practical applications.

CONCLUDING REMARKS

The main purpose of this paper is to formalize recognition and evaluation of errors that may occur in facies maps. The effect of errors of measurement and of judgment tends to become more noticeable as methods of facies map interpretation change from qualitative study of facies patterns and trends to quantitative evaluation of gradients, and to the use of maps as formal predicting devices.

The relatively rapid increase during the past few years in the use of high speed digital computers in handling masses of stratigraphic and facies data tends to free the geologist from time-consuming calculations, and allows more time for studying the full implications of his data. It seems inevitable that as this trend continues, premium will be placed on fuller analysis of the original data. Methods of analysis that are out of the question on a time and cost basis without computers become a matter of routine with the computers. In these more advanced methods of analysis questions of the reliability of the data, as far as errors of measurement and judgment are concerned, will rise in importance through their effects on the accuracy and precision of stratigraphic analysis.

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FIGS. 1–7, JUNE, 1958

CLAY MINERAL COMPOSITION OF RECENT SEDIMENTS FROM THE MISSISSIPPI RIVER DELTA[1]

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ABSTRACT

The clay mineral composition of Recent sediments from the modern Mississippi River Delta and offshore regions in the vicinity of the Delta is reported. Montmorillonite is the dominant clay mineral being deposited in the Delta region. A small amount of this component changes to illite and chlorite. It is suggested that this material represents degraded micaceous material undergoing regradation, and thus represents the approximate contribution of the Ohio River drainage system to clay mineral assemblage. The bulk of the montmorillonite, presumably bentonitic in character, undergoes no apparent diagenesis. It is suggested that this material represents the approximate contribution of the drainage basin of the Missouri River system.

INTRODUCTION

For the past several years, under the sponsorship of American Petroleum Institute Project 51, the authors have been engaged in a study of the clay mineral constituents in Recent sediments from the southeastern part of the Mississippi River Delta. Samples were collected by the staff of the Scripps Institution of Oceanography of the University of California as a part of their more extensive study of the sediments and oceanography of the area. Particular acknowledgement is given to Francis P. Shepard, Director of A.P.I. Project 51, who cooperated with and assisted the authors in many ways.

DESCRIPTION OF AREA

Figure 1 shows the general location of the area while figures 2 and 3 show the locations from which samples were obtained for clay mineral analyses. The area sampled is in the southeastern Mississippi River Delta region and extends from approximately 29° 30′ N. latitude to 29° 00′ N. latitude and from approximately 88° 55′ W. longitude to 89° 31′ W. longitude, including the area from Pass a Loutre on the south to Breton Sound on the north. It is apparent from figure 2 that most of the samples were collected from the very shallow shelf bordering the Mississippi River Delta on the east. Additional but fewer samples were collected further offshore in deeper water (fig. 3).

A brief description of some of the more important aspects of sedimentation and oceanography of the area, based on Scruton's (1955) and Shepard's (1956) extensive studies, are pertinent to the interpretation of the clay mineral distribution. Scruton and Shepard have subdivided the deposits of the area into textural sedimentary units which persist somewhat vertically and laterally and illustrate the process of deltal growth. Sediments to the east of the sub-aerial portion of the delta can be compared to the topset, foreset, and bottomset beds of the classical delta, although their angular discordance is slight. The sequence is especially well developed off Pass a Loutre. The distribution of these sedimentary units, following Shepard (1956), is shown in figure 4.

Sub-aerial portions of the delta consist of clayey-silt and silty marsh deposits containing abundant plant material. Close inshore and along the margins of the delta, particularly off the mouths of distributaries, laminated silts, sands, and clayey deposits occur. These *delta platform* marine sediments, along with the continental sediments which include deposits of the distributaries and swamp deposits, and deposits of interdistributary bays lying between deltal lobes constitute the equivalent of topset beds.

These sediments grade laterally into silty-clays of the *pro-delta slope* which is volumetrically the most important unit of the advancing delta. These silty-clays, analogous to foreset beds, occur in a narrow band east of the delta but to the south extend down the continental slope of the Gulf of Mexico. Their high clay and low sand contents distinguish the foreset from the topset beds. Stratification is generally poor.

Farther east off Pass a Loutre similar silty

[1] Manuscript received December 24, 1957.

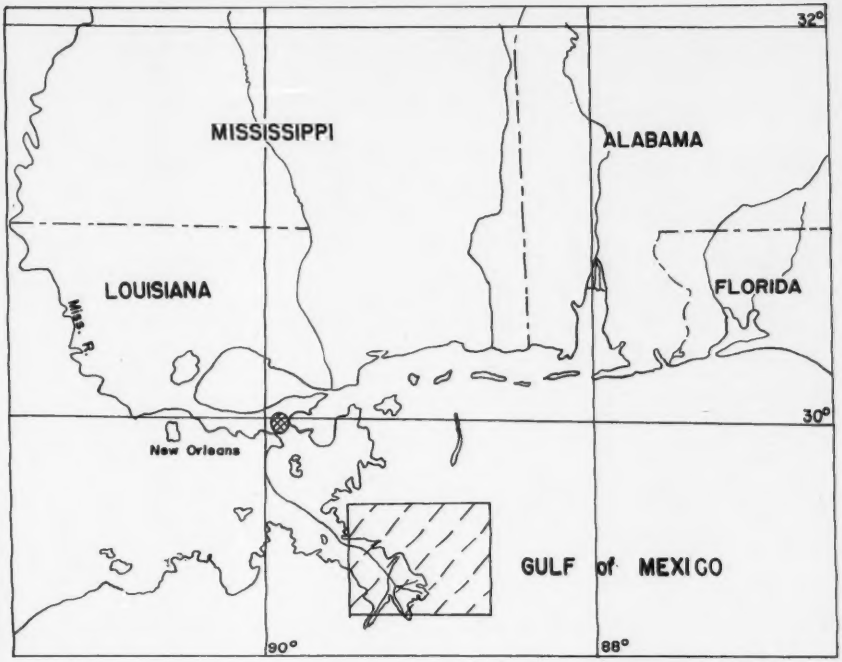

FIG. 1.—Map of the Mississippi River Delta region showing the area studied (cross-hatched).

clays represent the most seaward deposited sediments of strictly terrigenous origin, constituting, therefore, the most advanced unit of the growing delta. These *open shelf* sediments of the *recent delta* constitute the bottomset beds. Sediments of bottomset, like those of the foreset beds, are principally silty-clays with sand increasing away from the delta margin.

Still farther offshore is an area of predominantly sandy sediment which represents the platform of older sediment over which the delta is advancing. The *old shelf* deposits appear, according to Shepard (1956), to date back to a time of lowered sea level and display indications of having formed in shallow marine water.

In Breton Sound, off the Baptiste Collette sub-delta, the distribution of these textural units is much less regular and extremes of sediment type are found.

Scruton's (1955) study of surface and bottom chlorinites reveal the distribution and extent of mixing of Mississippi River and Open-gulf water masses. Even during periods of high river discharge, bottom chlorinites in the offshore area southeast of Breton Island are high (19–20 parts per thousand), indicating the presence of only slightly diluted open gulf water over the entire bottom. Inshore as far as the one fathom contour, bottom chlorinites were found to vary between 14 and 20 parts per thousand. At the surface, during periods of high runoff, chlorinites as low as 10 parts per thousand were recorded as far as 10 miles off Main Pass, showing that a relatively thin and well-defined layer of low chlorinity river water spreads seaward, overriding the denser bottom water. This surface layer is visually displayed by the observation of plumes of turbid water extending many miles offshore (Scruton and Moore, 1953).

Water within Breton Sound is a composite water mass resulting from more pronounced mixing of river and open-gulf waters throughout this shallow area. Thus, bottom chlorinites are intermediate in value

but show a considerable range related areally to the physiography of the region and temporally to fluctuations in movement of the main water masses. Thus Breton Sound is characterized by relatively great variation in salinity as well as sediment type.

ANALYTICAL PROCEDURE

Details of the sample preparation have been described in a previous publication (Grim and Johns, 1955). Briefly the process was as follows: samples, as received, were suspended in distilled water, filtered, and washed to remove soluble salts; the filtrate was saved and analyzed for sodium and potassium by flame photometry and for magnesium by the versenate method described by Cheng and Bray (1951); significant variations in cation ratios should give an indication of ions being subtracted from the water by diagenetic processes; sediment samples were then resuspended and the minus 1 micron fraction was collected by repeated sedimentation and decantation; the clay suspension was concentrated by evaporation and then allowed to settle on glass slides with the formation of oriented aggregates: the clay mineral constituents were identified by X-ray diffraction analysis, utilizing both recording X-ray spectrometer and conventional powder techniques.

FIG. 2.—Near shore sample locations. Boundaries (from Shepard, 1956) of sedimentary units indicated by heavy lines.

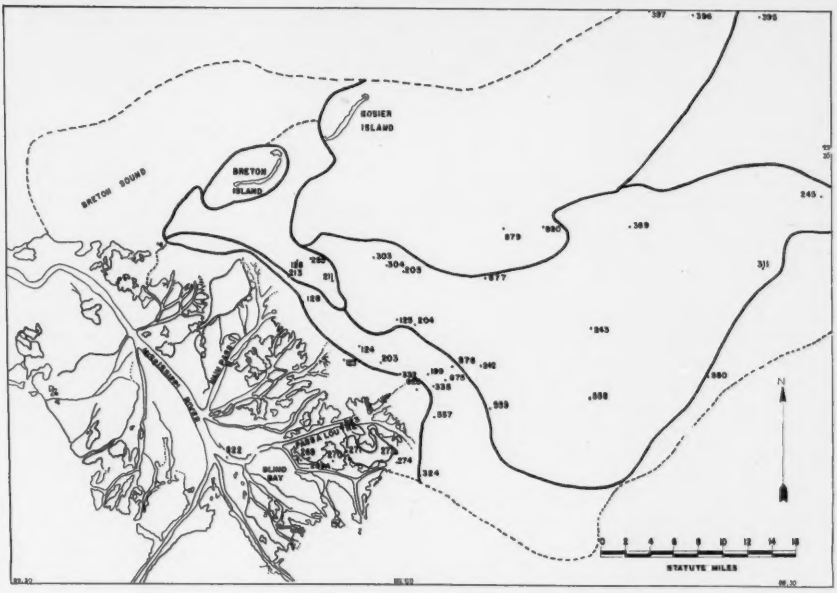

FIG. 3.—Offshore sample locations. Boundaries (from Shepard, 1956) of sedimentary units indicated by heavy lines.

The procedure used in the identification and quantitative estimations of the clay mineral components has been described in detail in a previous publication, Johns, Grim, and Bradley (1954).

Montmorillonite, present in all samples and most abundant in many, was identified by its rational sequence of basal orders of reflection related to 17 Å following treatment with ethylene glycol. Illite was identified as a component on the basis of characteristic reflections related to a 10 Å periodicity which remained unchanged following glycol treatment. Chlorite was established as a constituent of all samples by its diagnostic series of basal reflections related to 14 Å. The 14 Å reflection in the natural samples was obscured by a low angle maximum for the poorly crystalline montmorillonite component but was revealed following heat treatment to 450° C, by which temperature montmorillonite has collapsed. The chlorite component itself was unaffected by heating to 450° C. It was necessary to heat to 550° C to observe the changes in diffraction maxima which are characteristic of chlorite following heating, namely, an increase in the intensity of the 14 Å reflection and a decrease or extinction of higher orders. It was, therefore, impossible to confirm with certainty the presence or absence of small amounts of kaolinite in addition to chlorite. Accordingly these components are reported together as chlorite-kaolinite. Chlorite was, however, confirmed in all cases, and it is the authors' opinion that kaolinite, if present at all, is a very minor component.

CLAY MINERAL DISTRIBUTION

As a result of the complexity in sediment distribution pattern of the east Mississippi River Delta area, it was found advisable when considering the variations in clay mineral distribution to sub-divide the area. Boundaries, corresponding to Shepard's (1956) sedimentary units described earlier, were utilized. His terminology with some apparent exceptions, will be followed in characterizing these areas. Thus, samples from each of the following areas were grouped together and comprise a sequence denoting conditions of progressively increasing salinity: suspended sediment (Baton

Rouge), river channel, Baptiste Collette sub-delta and inner Blind Bay, interdistributary bays, delta platform, pro-delta slope, open lagoon (Breton Sound), open lagoonal inlet, open shelf (recent delta), old shelf, and reworked Mississippi delta.

Estimates of clay mineral constituents expressed in most probable parts in ten are tabulated in table 1 for surface samples. Average values for each component for each sedimentary unit are also shown in table 1 and the data are plotted graphically in figure 5. In addition, the range in clay mineral composition within a given sedimentary unit is shown in figure 5.

The samples of river sediment and especially samples collected upstream (beyond the influence of the salt water wedge) at Baton Rouge most closely represent source material for the deltal area. The particularly high montmorillonite and low illite and chlorite-kaolinite contents of these sediments is noteworthy. It is apparent from figure 5 that the average montmorillonite content decreases slightly but abruptly upon contact with saline water.

This initial decrease in montmorillonite is accompanied by a commensurate increase in chlorite-kaolinite and illite. Following these initial changes in mineralogical composition there is no significant variation further seaward. The reciprocal relation between abundance of illite and chlorite-kaolinite and the abundance of montmorillonite is the most noteworthy feature of the clay mineral distribution in this area.

A limited amount of additional mineralogical data is available with regard to vertical changes in clay mineralogy. Clay mineral data for samples from a number of relatively short cores from a number of the areas studied are given in table 2. There is no evidence of any significant systematic variation in mineralogy with depth in any of these individual cores. Moreover, if one compares, for a given area, average compositions of all

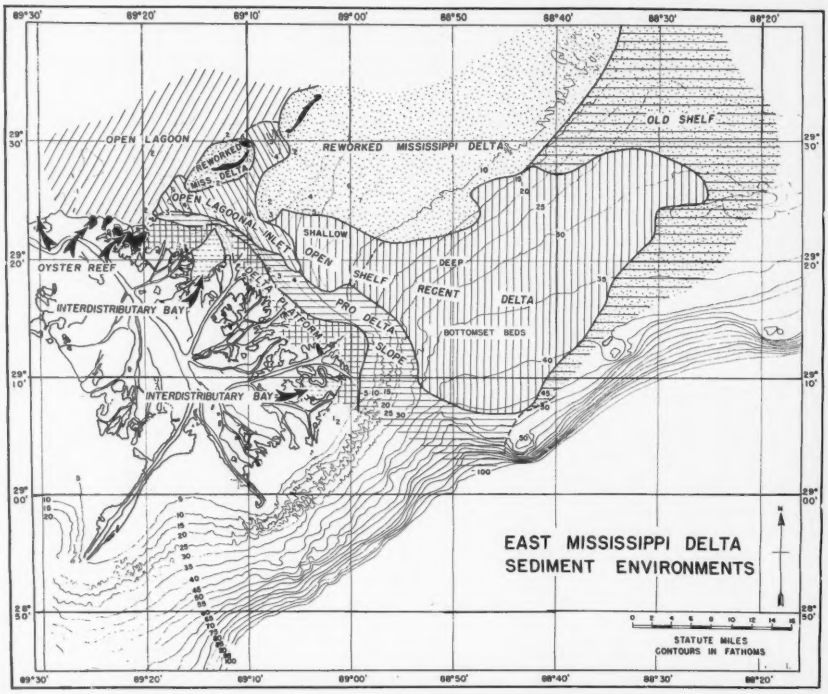

FIG. 4.—Sedimentary units of Delta area (from Shepard, 1956).

TABLE 1.—*Bottom samples. Clay mineral composition and interstitial water analyses*

Sample	Depth	Mont.	Illite	Chlor-Kaol.	Na/K	Na/Mg
River Sediments						
Baton Rouge	Surface	7.5	1.0	1.0	5.0	1.2
822	Surface	6.5	1.5	1.5	5.0	11.2
823	Surface	6.5	1.5	1.5	10.0	7.5
MP6	Surface	5.0	2.5	1.5	—	—
Average		6.5	1.5	1.5	6.7	6.7
Baptiste Collette Sub-delta and Inner Blind Bay						
BC 215	Surface	5.5	2.0	1.5	12.5	27.8
BC 217	Surface	4.0	3.0	2.0	30.0	33.3
BC 218	Surface	5.0	3.0	1.0	—	—
BC 224	Surface	5.5	2.0	2.0	18.8	35.7
BC 236	Surface	5.0	2.5	2.0	20.0	15.9
BB 269	Surface	6.0	1.5	2.0	1.5	2.5
BB 269a	Surface	5.0	2.5	2.0	2.5	2.6
BB 270	Surface	5.5	2.0	1.5	3.0	1.7
Average		5.2	2.3	1.7	12.5	17.1
Interdistributary Bays						
BC 137	6 cm	5.5	2.0	1.5	20.0	30.9
BC 248	Surface	4.0	2.5	2.5	15.0	12.5
BC 250	Surface	6.0	2.0	1.5	20.0	66.6
BC 251	Surface	5.0	1.5	2.5	—	—
BC 252	Surface	5.5	2.5	1.5	10.0	16.7
BC 253	Surface	5.5	2.0	1.5	6.0	10.0
BC 257	Surface	5.0	2.0	1.5	12.9	15.0
BC 258	Surface	5.5	3.0	0.5	30.0	7.1
BC 260	Surface	5.5	2.0	1.5	14.0	14.0
BC 264	Surface	6.0	1.5	1.5	6.0	3.3
BB 271	Surface	4.5	2.0	2.5	6.0	10.0
BB 273	Surface	5.5	2.0	1.5	12.0	13.3
Average		5.3	2.1	1.7	13.8	18.8
Delta Platform						
BS 83	0–19 cm	3.0	3.0	3.0	19.2	29.5
MP 123	Surface	5.0	2.5	2.0	17.0	25.8
BS 165	5–10 cm	4.5	2.5	2.0	15.7	28.2
BS 172	0–19 cm	5.5	2.0	2.0	17.1	41.3
MP 263	Surface	2.0	2.5	3.0	15.0	33.4
BC 265	Surface	5.0	1.5	2.5	5.0	16.7
BB 274	Surface	5.0	2.0	2.0	18.0	15.0
MP 287	Surface	3.0	3.5	3.0	30.0	37.5
MP 288	Surface	5.5	1.5	2.0	23.1	29.6
MP 296	Surface	4.0	2.5	2.5	10.0	38.8
MP 297	Surface	5.5	2.0	1.5	31.4	36.6
MP 298	Surface	4.5	2.0	2.0	22.8	37.9
MP 299	Surface	4.5	2.0	2.5	21.0	25.0
MP 302	Surface	2.0	4.0	3.0	27.6	57.5
332	Surface	5.5	2.0	1.0	—	—
825	Surface	6.0	1.5	1.5	17.5	5.9
Average		4.5	2.3	2.2	19.4	29.9

TABLE 1.—*Continued*

Sample	Depth	Mont.	Illite	Chlor-Kaol.	Na/K	Na/Mg
Pro-Delta Slope						
BS 23	5–10 cm	4.5	2.0	2.0	16.1	25.0
MP 124	0–4 cm	5.0	2.0	2.0	16.4	23.1
MP 128	Surface	4.5	2.5	2.0	18.0	41.6
BS 166	0–19 cm	5.5	1.5	1.5	16.6	45.2
BS 171	Surface	5.0	2.0	1.5	13.4	19.0
PL 199	Surface	5.0	2.0	1.5	21.4	31.2
PL 203	Surface	5.0	2.0	2.0	20.5	31.6
MP 213	Surface	6.0	2.0	2.0	19.3	—
MP 292	Surface	5.0	1.5	2.0	15.0	15.8
MP 294	Surface	6.0	1.5	1.5	19.0	19.1
MP 300	Surface	5.0	2.5	1.5	12.2	26.2
324	10 cm	5.0	2.5	1.5	11.6	58.4
335	Surface	5.0	2.5	1.5	22.0	22.9
PL 557	Surface	4.0	3.0	2.0	—	—
875	Surface	6.5	1.5	1.0	8.3	50.0
876	Surface	6.5	1.5	1.0	—	—
Average		5.2	2.0	1.7	16.4	31.3
Open Lagoon						
BS 30	5–10 cm	6.0	2.0	1.0	10.5	16.7
BS 107	Surface	4.5	3.0	1.5	15.7	48.6
BS 108	Surface	4.0	3.5	2.0	10.6	11.5
BS 110	Surface	6.5	1.5	1.0	11.8	10.3
BS 111	104–126 cm	5.0	2.5	1.5	13.6	22.6
BS 112	Surface	3.0	2.5	4.0	10.6	12.8
BS 116	Surface	3.0	2.5	3.5	11.5	12.1
BS 151	Surface	5.5	1.5	1.5	13.9	21.4
BS 152	Surface	4.5	1.5	3.0	10.5	27.8
BS 159	Surface	6.0	2.0	1.0	12.2	22.9
BS 160	Surface	5.5	1.5	2.0	13.6	19.2
BS 161	Surface	6.0	1.5	1.5	18.6	28.2
BS 162	Surface	5.5	2.0	1.0	14.6	18.6
BS 164	Surface	3.5	2.5	3.0	11.5	16.2
BS 185	Surface	6.0	1.5	1.0	14.6	18.9
Average		5.0	2.0	1.9	12.9	20.5
Open Lagoonal Inlet						
MP 126	Surface	5.0	1.5	2.5	17.3	18.1
BS 163	Surface	6.0	2.5	1.0	16.7	39.4
BS 167	0–19 cm	4.5	2.5	2.5	12.1	20.3
BS 168	Surface	5.5	1.5	2.0	—	—
BS 170	Surface	4.5	2.5	2.0	13.4	21.1
BS 184	Surface	5.5	2.0	2.0	14.5	37.3
MP 211	Surface	5.5	2.0	2.0	16.0	20.5
BI 276	Surface	4.5	2.0	3.0	22.8	20.5
BI 278	Surface	5.0	2.0	2.0	20.0	15.8
BI 279	Surface	6.0	1.5	1.5	13.6	22.7
BI 280	Surface	4.0	3.0	2.0	18.8	35.7
BI 281	Surface	5.0	2.5	1.0	25.6	27.1
MP 282	Surface	5.5	2.0	2.0	14.0	33.3
MP 283	Surface	5.5	1.5	1.5	26.4	22.0
MP 285	Surface	4.0	1.5	3.5	21.4	20.8
MP 290	Surface	5.5	2.0	2.0	15.0	21.2
Average		5.1	2.0	2.0	18.2	23.7

TABLE 1.—*Continued*

Sample	Depth	Mont.	Illite	Chlor-Kaol.	Na/K	Na/Mg
Open Shelf Recent Delta						
MP 125	Surface	5.0	2.0	2.0	15.0	21.4
PL 204	Surface	5.5	2.0	2.0	13.4	25.4
PL 205	Surface	5.0	2.0	1.5	8.8	21.8
PL 242	Surface	4.0	2.5	2.5	11.1	19.9
PL 243	Surface	4.0	2.5	2.0	9.1	15.2
PL 245	Surface	5.0	2.5	1.5	—	18.0
MP 303	Surface	5.5	2.5	1.0	20.0	13.3
MP 304	Surface	4.5	3.0	2.0	14.1	14.2
GM 311	Surface	4.5	2.5	2.0	11.6	16.0
369	Surface	6.0	2.0	1.5	12.6	39.9
PL 558	Surface	5.5	2.5	1.0	9.1	11.9
PL 559	Surface	4.0	3.5	1.5	—	—
877	Surface	5.0	2.0	2.0	8.7	—
Average		5.0	2.4	1.6	11.5	19.7
Reworked Mississippi Delta						
BS 122	Surface	5.0	2.0	1.5		
BS 182	Surface	6.0	1.5	2.0		
BI 277	Surface	6.0	2.0	0.5		
396	6–11 cm	4.5	2.5	2.5		
397	Surface	5.5	2.0	1.5		
879	Surface	7.0	1.0	1.0		
880	Surface	6.0	1.0	2.0		
Average		5.7	1.7	1.6		
Old Shelf						
395	Surface	5.5	2.0	1.5		
PL 560	Surface	3.0	3.5	2.5		

surface samples with average compositions for all core samples, no significant difference is apparent, and thus no diagenetic effects are suggested within the short column of sediment studied.

DISCUSSION

The noted decrease in montmorillonite with commensurate increase in illite and chlorite upon contact with saline water is certainly suggestive of diagenetic formation of the latter two minerals from montmorillonite, the potassium and magnesium required having been abstracted from the sea water. Consideration of Na/K and Na/Mg ratios of interstitial water as averaged for each sedimentary unit are revealing in this respect. These data are tabulated in table 1 and are plotted graphically in figure 6. These ratios express the relative proportions of the cations present in the "static" water intimately associated with the sedimentary material. Variations in these ratios give an indication of potassium and magnesium being removed from the interstitial water relative to sodium. The cation ratio curves (fig. 6) exhibit maxima in the delta platform and pro-delta slope regions where clay accumulation is volumetrically most important. As a result of simple mixing of fresh and sea water, cation ratio curves would show continuous increases seaward, without maxima. Thus it is evident that potassium and magnesium are in fact being abstracted preferentially from sea water and is undoubtedly being made available in exchange positions for further fixation leading to the formation of illite and chlorite. Comparison of figures 5 and 6 show, however, that although illitization and chloritization occur and reach their maximum almost immediately upon contact with saline water, removal of potassium and magnesium from the sea water continues as the sediment is swept farther seaward. Undoubtedly montmorillonite which has not changed noticeably to illite or chlorite does through cation exchange take up potassium and magnesium

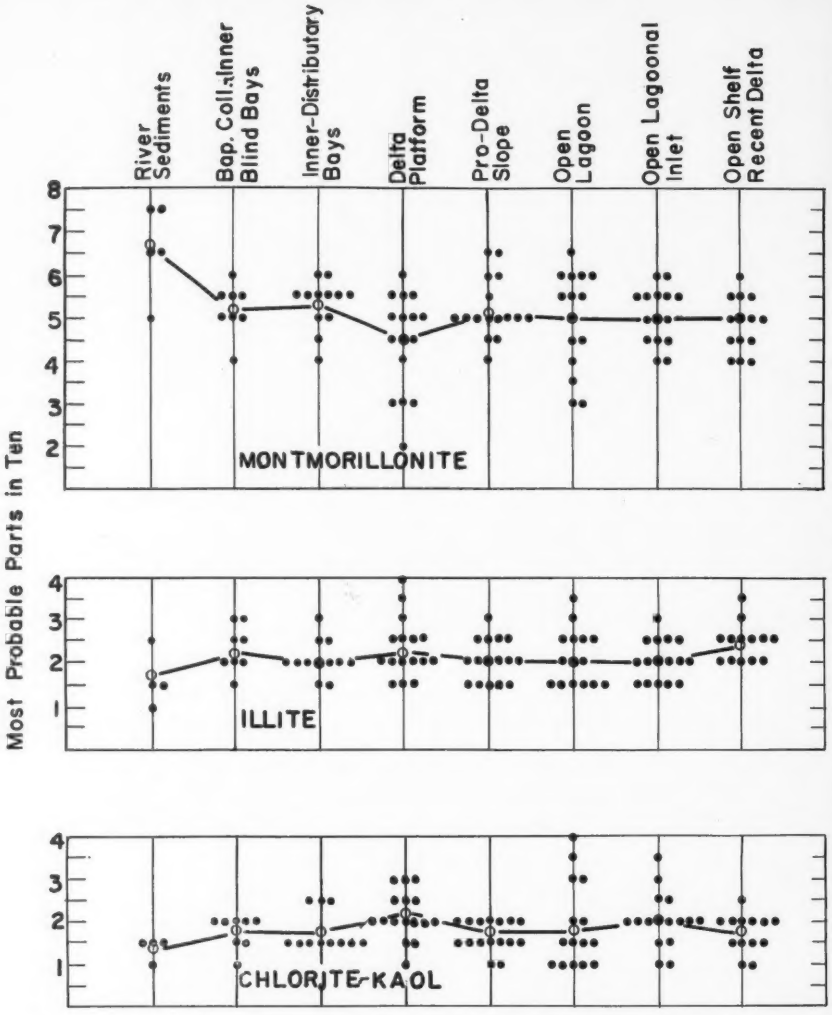

FIG. 5.—Clay mineral distributions within sedimentary units. ○—Average values for each unit; ●—values for each sample.

from the water. Chemical data (table 3) for the clay fractions of a number of delta samples bear this out. The K_2O contents, particularly for those samples from the strictly marine environment, appear to be too high for the illite contents encountered in this study. It seems likely that this can be at least partially accounted for by the presence in the montmorillonite of appreciable potassium. A one-to-one correlation between K_2O content and illite content can not be expected. In figure 7, Al_2O_3/K_2O ratios are plotted as a function of illite and montmorillonite content using the data tabulated in table 3. Al_2O_3/K_2O is used rather than K_2O to take into account small

TABLE 2.—*Core samples. Clay mineral composition and interstitial water analyses*

Sample	Depth	Mont.	Illite	Chlor-Kaol.
Baptiste Collette Sub-Delta				
BC 215	0 cm	5.5	2.0	1.5
	25	5.5	1.5	1.5
	75	6.0	1.5	1.5
	125	6.5	1.5	1.0
BC 217	0 cm	4.0	3.0	2.0
	100	5.5	1.5	1.5
	125	5.0	1.5	1.5
	150	6.0	2.0	1.0
	175	5.5	2.0	1.5
	200	—	—	—
BC 218	0 cm	5.0	3.0	1.0
	25	5.0	3.0	1.0
	75	5.0	2.0	2.0
	100	6.0	1.5	2.0
	125	6.0	1.5	1.5
BC 224	0 cm	5.5	2.0	2.0
	25	—	—	—
	75	4.5	3.0	1.5
	100	5.5	2.5	1.5
	125	—	—	—
BC 236	0 cm	5.0	2.5	2.0
	25	7.0	1.5	1.0
	50	6.5	1.5	1.0
Average		5.6	2.1	1.5
Delta Platform				
825	0 cm	6.0	1.5	1.5
	30	6.5	1.0	1.0
	50	7.0	1.0	1.0
Average		6.5	1.2	1.2
Pro-Delta Slope				
MP 124	0 cm	5.0	2.0	2.0
	160	5.0	2.5	1.0
MP 128	0 cm	4.5	2.5	2.0
	40	6.0	2.0	1.0
	130	4.0	3.0	2.5
PL 324	10 cm	5.0	2.5	1.5
	50	3.5	3.5	2.0
	65	4.5	3.0	2.0
	70	4.0	2.5	2.5
	100	4.0	3.0	2.0
	105	4.0	3.5	1.5
PL 557	0 cm	4.0	3.0	2.0
	15	3.5	2.5	2.5
	30	5.0	2.5	1.5
	60	5.0	2.5	1.5
	120	4.5	3.0	1.5
	160	5.0	2.0	1.5
875	0 cm	6.5	1.5	1.0
	63	6.0	1.5	1.5
876	0 cm	6.5	1.5	1.0
	106	7.0	1.0	1.0
Average		4.9	2.5	1.7

TABLE 2.—*Continued*

Sample	Depth	Mont.	Illite	Chlor-Kaol.
Open Lagoonal Inlet				
MP 126	0 cm	5.0	1.5	2.5
	40	5.5	1.5	1.5
	130	5.0	2.5	1.5
Average		5.2	1.8	1.8
Open Shelf Recent Delta				
MP 125	0 cm	5.0	2.0	2.0
	40	4.0	1.5	3.0
PL 242	0 cm	4.0	2.5	2.5
	40	4.0	2.5	2.5
	130	4.0	2.5	2.5
	240	4.5	3.0	1.5
PL 243	0 cm	4.0	2.5	2.0
	40	5.0	2.5	1.5
	130	5.0	2.5	2.0
	280	5.0	2.0	2.0
PL 245	0 cm	5.0	2.5	1.5
	40	4.5	3.0	1.5
	80	5.0	2.5	2.0
	130	5.0	2.5	1.5
	200	5.0	2.5	1.5
	260	5.0	2.5	1.5
PL 558	0 cm	5.5	2.5	1.0
	15	4.0	2.5	2.0
	30	4.5	2.5	2.0
	60	3.5	3.0	2.0
	120	4.5	3.0	1.5
	240	3.5	3.0	2.5
PL 559	0 cm	4.0	3.5	1.5
	15	4.0	3.0	2.0
	30	4.0	3.0	2.0
	60	3.0	3.5	2.0
	120	4.5	2.5	2.5
	150	3.5	3.0	2.5
877	0 cm	5.0	2.0	2.0
	4–6	6.5	1.5	1.5
Average		4.5	2.6	1.9
Reworked Mississippi Delta				
879	0 cm	7.0	1.0	1.0
	10	7.0	1.0	1.0
880	0 cm	6.0	1.0	2.0
	28	6.0	1.5	1.5
Average		6.5	1.1	1.4
Old Shelf				
PL 560	0 cm	3.0	3.5	2.5
	15	—	—	—
	30	3.5	3.0	2.0
	60	2.0	4.0	3.0
	120	3.0	3.5	2.5
	195	3.5	3.0	2.0
Average		3.0	3.4	2.4

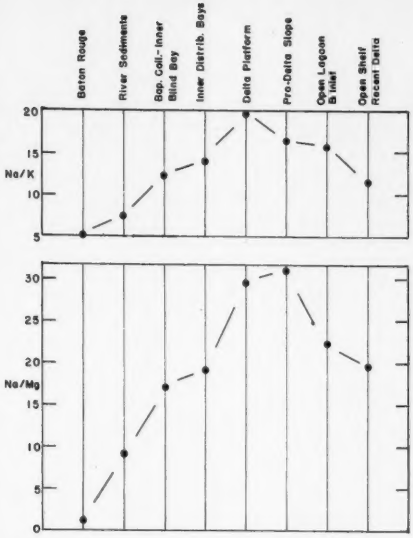

FIG. 6.—Distribution of average values of Na/K and Na/Mg for interstitial water for each sedimentary unit.

variations in non-clay mineral content. In spite of the scatter of points the correlation between K_2O and illite and montmorillonite contents is apparent.

Al_2O_3/Na_2O ratios are also plotted in figure 7. The correlation between Na_2O and illite suggests that sodium along with potassium is being fixed by illite. It is possible that the Na/K ratio of a sediment may prove indicative of its environment of sedimentation. Such chemical studies are currently being carried out in one of the writer's (W.D.J.) laboratories.

The chemical data are also interesting in another respect. The Fe_2O_3 content is uniformly higher, by a factor of about two, than that generally found in ancient argillaceous sediments. No explanation of this high iron content is apparent.

It is impossible to consider in a similar manner the MgO analyses since, in addition to serving as exchange cations, magnesium is a significant constituent of the silicate layer structure. Thus it appears likely that the areal variations in clay mineral composition, though slight, are the result of early diagenesis, as has been noted elsewhere (Grim, Dietz, and Bradley, 1949; Grim and Johns, 1955; Powers, 1955).

Perhaps the most significant aspect of the clay mineral distribution in the Mississippi Delta area is not so much the change noted, but that the diagenesis was of such a low order of magnitude. In light of earlier studies of recent sediments off the Texas coast at Rockport (Grim and Johns, 1955) and off the California coast (Grim, Dietz, and Bradley, 1949), it might be expected that montmorillonite would have experienced considerably greater diagenetic change than observed in the Delta area. At Rockport the source material contains montmorillonite in about the same order of abundance as sediment transported by the Mississippi River. In the Rockport area approximately two-thirds of the original montmorillonite transformed under marine conditions to illite and chlorite. Changes of the same order of magnitude were observed off the California coast. As noted for the Mississippi Delta area, only about 25 percent of the original montmorillonite underwent change, as represented by a reduction of montmorillonite from an average of 65 to 50 percent. These differences can be interpreted in terms of a number of factors. Taking into consideration the exceptionally high rate of sedimentation in the Delta area as compared to the Texas and California areas, it can be rationalized that lack of time for adjustment to prevailing chemical environment may account for the low order of change noted. Likewise the higher salinities which prevail in the Texas lagoons might have accounted for the more pronounced changes observed there.

Undoubtedly the foregoing factors have played a role in determining clay mineral assemblages in Recent sediments from different areas. It appears likely that still another sometimes more important factor is prevalent here, namely difference in the nature of the source material.

Considering the source of sediment carried by the Mississippi River to the Gulf of Mexico, there are two major areas contributing sediment, the drainage basins of the Missouri and the Ohio Rivers. The general nature of the soils developed in each of these two basins have been established with some degree of certainty. Soils of the Missouri drainage basin in the High Plains region have developed in large part from Mesozoic and Cenezoic sediments which

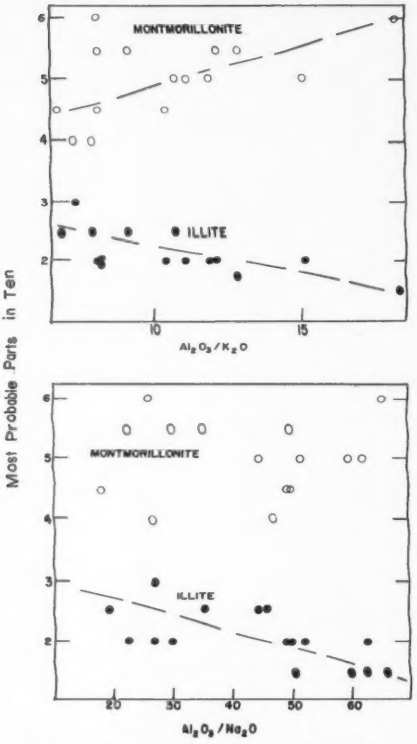

FIG. 7.—Correlation between montmorillonite and illite content and Al_2O_3/K_2O and Al_2O_3/Na_2O for analyzed clay fractions.

contain much montmorillonite and are in places bentonitic. The vast loess deposits of this region contribute in large measure to stream sediments and these have been shown over wide areas to contain montmorillonite as the chief clay mineral. The arid and semi-arid climatic conditions, low rainfall, and relatively little leaching of the soil of the region results in the development of chernozems under conditions leading to the formation and preservation of montmorillonitic minerals.

The area drained by the Ohio River and its tributaries, on the other hand, is underlain in large measure by Paleozoic sediments containing argillaceous constituents which are dominantly illitic and chloritic.

The Pleistocene glacial deposits from which many of the soils of this area have developed are likewise largely illitic and chloritic. Studies of the forest soils of this area have indicated that weathering conditions lead to degradation of these micaceous materials, resulting in the formation of vermiculitic and montmorillonitic (at least expanding) minerals. Extensive transportation of these materials would be expected to result in even further degradation by removal of potassium and magnesium from between silicate layers.

From these two major drainage basins the Mississippi River carries to the Gulf montmorillonite and degraded illites and chlorites, both of which are expandable and would normally be identified as montmorillonite. The degraded materials would be expected to readily pick up potassium and magnesium and regrade to illite and chlorite. Reconstitution would probably be about contemporaneous with deposition. Powers (1955), studying diagenesis in Chesapeake Bay sediments, noted that reconstitution of degraded illites and chlorites does occur in a marine environment as described above. The marked changes in crystallinity of marine sediments off the North Carolina coast as studied by Murray and Sayyab (1955) are likewise a manifestation of the same regenerative process.

It is suggested that the slight but abrupt change in montmorillonite to illite and chlorite observed in this study is the result of reconstitution of degraded materials in the manner described above. It is also suggested that the montmorillonite which experienced change represents the approximate contribution of the Ohio drainage basin to the total of clay mineral components reaching the Gulf. The montmorillonite contributed by the Missouri Basin dominates and under the conditions prevailing experiences essentially no change other than simple cation exchange. This is based on the assumption that the expandable material from the Missouri River area is a different type from that of the Ohio River Basin. The former material is true montmorillonite or "bentonitic" montmorillonitic, whereas the latter is degraded mica. It becomes apparent then that as far as the argillaceous constituents are concerned the ratio of the contribution from the Missouri and Ohio basins to the northern Gulf of Mexico is of the order of about four to one. This is not at all unreasonable in light of

TABLE 3.—*Chemical analyses by spectrographic procedure on clay fraction of selected bottom samples. Analyses made after heating to 500° C for 15 minutes. SiO_2 obtained by difference*

	BB 269	BC 215 (Surf)	BC 215 (125 cm)	BC257	BB 274	MP 299	PL 242	PL 557	PL 558
Al_2O_3	24.6	23.6	25.7	25.0	23.8	25.9	22.7	22.8	23.1
Fe_2O_3	8.8	8.2	7.35	8.3	9.0	8.1	8.35	8.7	7.2
TiO_2	0.67	0.72	0.76	0.75	0.74	0.74	0.69	0.76	0.63
MgO	2.45	2.50	2.85	3.05	2.45	2.55	2.50	2.90	2.45
CaO	5.1	1.80	0.70	0.95	3.35	1.70	1.10	2.25	4.65
Na_2O	0.37	1.05	0.41	0.42	0.45	0.53	0.48	0.87	0.65
K_2O	1.35	1.95	2.35	1.65	2.15	2.50	2.85	3.10	2.55
Al_2O_3/K_2O	18.3	12.1	10.9	15.1	11.1	10.4	7.9	7.3	9.1
Al_2O_3/Na_2O	66.6	22.5	62.6	59.6	52.4	48.9	47.2	26.2	35.5

	GM 311	PL 205	369	BS 160	PL 244	BI 276	395	BI 281
Al_2O_3	23.2	23.8	23.2	23.7	26.1	23.4	20.6	25.0
Fe_2O_3	7.55	8.2	7.85	7.65	7.7	8.55	8.0	8.05
TiO_2	0.65	0.72	0.63	0.71	0.73	0.68	0.69	0.66
MgO	3.15	2.60	2.70	3.10	2.80	2.90	2.55	3.10
CaO	3.00	2.10	2.20	2.45	5.0	2.55	1.40	3.80
Na_2O	1.25	0.38	0.85	0.47	0.32	0.47	0.68	0.56
K_2O	3.45	2.05	2.85	1.85	1.80	2.75	2.55	2.35
Al_2O_3/K_2O	6.7	11.9	8.1	12.8	14.5	8.5	8.1	10.7
Al_2O_3/Na_2O	18.5	62.6	27.3	50.4	81.5	49.9	30.3	44.6

existing knowledge of the relative contribution of total sediment from each of these major areas.

It is interesting that the delta sediments clearly reflect conditions in only a part of the source area and not in the adjacent area or even in the major part of the source area. Interpretations of conditions in the source area from clay mineral characteristics of sediments obviously must be made with caution and could be incompatible with similar interpretations based on the coarser constituents of the sediment which are likely to have much more local origin and thus represent a completely different source area.

It can be concluded, therefore, that numerous factors affect the clay mineral assemblege which forms or persists in argillaceous sediments. It is difficult even in Recent sediments where parameters can be more readily defined to fully evaluate the relative importance of source and environmental factors. It is apparent that for ancient sediments much more careful and detailed work is necessary before diagnostic criteria of petrogenetic significance can be developed.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 2, PP. 200–202
FIGS. 1–3, JUNE, 1958

ETCHING TECHNIQUE FOR USE ON THIN SECTIONS OF LIMESTONES[1]

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ABSTRACT

A method of making replicas of thin sections of limestones etched with acetic acid is described. This has been found to have the following important advantages over existing staining and etching techniques:

1.—Calcite textures are preserved in detail.
2.—Insoluble minerals are left standing in their original positions so that:
a.—their distribution is readily seen, and
b.—they may be removed for precise identification if necessary.

INTRODUCTION

Many methods have been used to locate and identify the non-calcitic minerals, particularly other carbonates which are present in limestones. The distinction and precise identification of dolomite is of particular importance in this respect, stains having been used to detect its presence with only varying degrees of success. Even if staining is successful and the non-calcitic parts remain unaffected the most one can usually say is that the unstained areas, if carbonate, are not calcite. Further refinement of identification is difficult.

Differential etching techniques, although simple and rapid, appear to have been but little used in limestone petrology. Surface etching, as described in detail by Lamar (1950), is useful where the determination of the distribution of the insoluble minerals is the major object. The immediate textural setting of such minerals is, however, destroyed. Acetate peels from lightly etched surfaces serve to indicate textural features but give little information concerning the insolubles.

The etching technique to be described has the advantages that non-calcitic elements of the rock are left standing in their original position in the rock and that they may be removed if necessary for further examination.

PROCEDURE

1.—The rock slice is ground and polished smooth with "Aloxite" (or a similar fine abrasive) on the side to be mounted.

2.—The slice is immersed in 20% acetic acid for about 5 minutes and then thoroughly washed and dried.

3.—The prepared side is mounted downwards on a slide using a resin as mountant (for example, Lakeside No. 70C). *Mounts on Canada Balsam are not successful.*

4.—The section is ground down to 30μ, the final stages being done with "Aloxite."

5.—The whole section is then placed in 20% acetic acid and the calcite completely dissolved away.

DISCUSSION

Acetic acid was used in preference to hydrochloric because it etches more selectively and does not attack the non-calcitic carbonates so readily. Lamar (1950) states that the action of acetic acid "appears to be considerably influenced by porosity, incipient fractures, grain contacts, size and relative purity of calcite grains, and other characteristics." While this may tend to over-emphasize features not apparent in normal thin section it is better than the more uniform etch achieved by hydrochloric acid.

The etching prior to mounting attacks the rock sufficiently for the resin to penetrate into the slice when mounted. Thus, when the procedure is completed and the remaining calcite removed, the texture of the original surface is faithfully preserved in detail in the resin. This replica of the limestone surface is best seen on a dry mount using reflected light or transmitted light and crossed nicols.

[1] Manuscript received January 30, 1958.

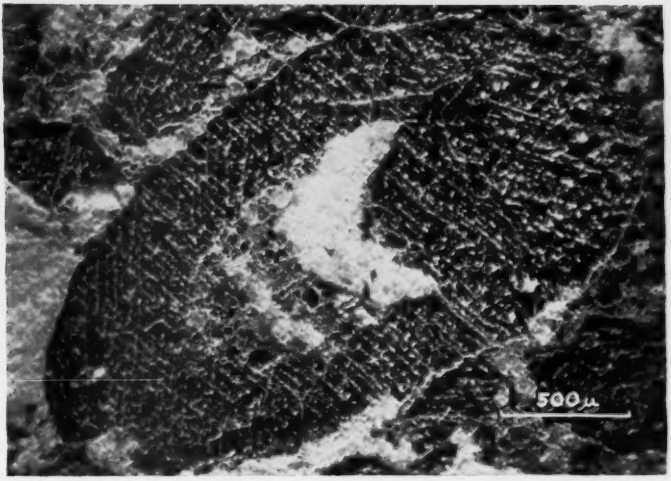

FIG. 1.—Lower Viséan Reef Limestone. Co. Clare, Eire. A crinoid ossicle showing well-marked cleavages in a limestone much of which is dolomitized. Dolomite appears as large white patches. The centre of the ossicle is partly composed of a fine-grained calcite mosaic, and is partly dolomitized. Photomicrograph of replica of etched surface. Reflected light. ×40.

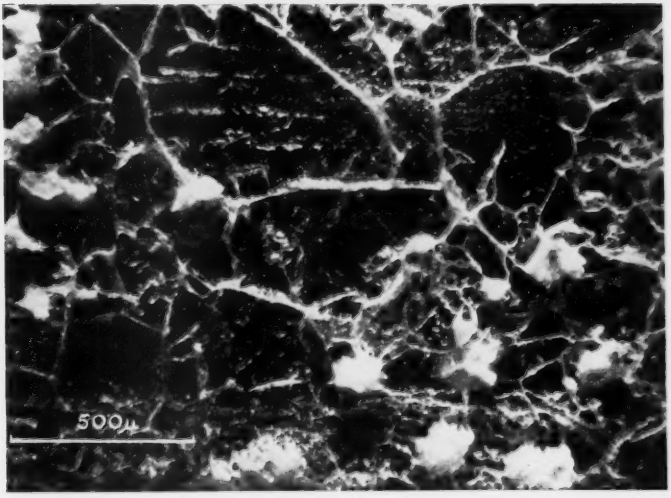

FIG. 2.—Lower Viséan limestone. Co. Limerick, Eire. A varigrained calcite mosaic, some of the crystals showing cleavage. The white patches are dolomite crystals. Photomicrograph of replica of etched surface. Reflected light. ×57.

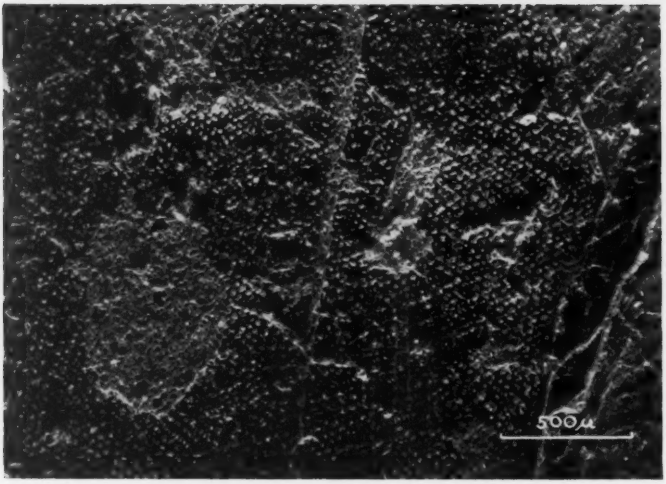

FIG. 3.—Lower Viséan Reef Limestone. Co. Clare, Eire. A crinoid ossicle with the stereome preserved. Fine-grained calcite mosaics occur in patches. This illustrates well the differential etching achieved by acetic acid on calcites of different degrees of purity. Photomicrograph of replica of etched surface. Reflected light. ×40.

The major disadvantage of etching, namely the loss of the calcite, is counterbalanced by the preservation of the general texture of the rock and details of individual crystals such as the cleavage. In many cases this proves to be a definite advantage since the texture is more clearly seen than in a normal thin section of limestone when the distinctness of the crystal boundaries depends on their orientation with respect to each other.

The non-calcitic minerals left standing in the resin are seen in their original positions relative to the rest of the section and can be examined by normal optical means. Such optical examination is facilitated if the section is flooded with water. In addition to this, individual crystals may be removed from known positions in the slice and examined further. This is especially important in the case of the non-calcitic carbonates when refractive index determinations are essential.

This technique has been used on limestones of various degrees of coarseness and has been found to render detail correctly even down to grain sizes of calcite-mudstone grade (5μ and less).

Some of the results obtained using this method are illustrated in figures 1, 2 and 3. These indicate the delicate nature of the acetic acid etch and the faithfulness of the reproduction on the replica surface.

ACKNOWLEDGEMENTS

I wish to express my thanks to Dr. F. Hodson who originally suggested the method which has been developed and is presented here and to Professor P. Allen who has kindly sponsored this paper and given helpful criticism during its preparation.

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JUNE, 1958

COMPARISON OF PHI PERCENTILE DEVIATIONS[1]

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ABSTRACT

Any phi percentile measure of deviation can be constructed according to $D_k = 1/k\ (P_a - P_b)$, where P_a and P_b are selected percentiles, and k is the number of standard deviations involved and is dependent on a and b. Measures constructed in this fashion are directly comparable with each other. As a measure of maximum homogeneity, one can use the maximum value of D_k.

One of the best-known measures of sorting is Trask's coefficient, *So*, which is the square root of the ratio between the quartiles of the size distribution. Other measures have been based on the numerical difference, in phi units, between two specified points on the size distribution curve. These phi measures are not directly comparable[2] with *So*. It would be advisable, however, to construct the various phi measures so that they can be compared directly with each other. To date this has not been done generally.

Inman (1952) adopted the standard deviation, obtained by a graphic approximation, as follows:

$$\sigma_\phi = \tfrac{1}{2}(\phi_{84} - \phi_{16}).$$

This had been proposed previously by Krumbein (1938) and Otto (1939). Because it is calculated from the sixteenth and eighty-fourth percentiles, it covers about 68 percent of the population, and therefore represents one standard deviation on each side of the mean (that is, a total spread of two standard deviations).

Griffiths (1951) used the percentile deviation, obtained as follows:

$$D_\phi = \tfrac{1}{2}(P_{90} - P_{10}).$$

This parameter covers 80 percent of the curve, and hence extends to 1.28 standard deviations on each side of the mean. It therefore has a total spread of 2.56 standard deviations. According to ordinary practice it would be rewritten:

$$D_\phi = \frac{1}{2.56}\,(P_{90} - P_{10}).$$

Likewise a deviation based on the fifth and ninety-fifth percentiles covers a total of 3.29 standard deviations, and should be written

$$D_\phi = \frac{1}{3.29}\,(D_{95} - D_{05}).$$

The parameters defined above can be distinguished by writing them D_2, $D_{2.56}$, $D_{3.29}$, or by any other suitable identification.

TABLE 1.—*Values for selected measures of deviation (Dixon and Massey, 1957, p. 381)*

Number of Standard Deviations Covered	Percent of Spread	Range, in Percentiles
2	68.27	16 to 84
2.564	80	10 to 90
3	86.64	07 to 93
3.29	90	05 to 95
3.92	95	2.5 to 97.50
4	95.45	2.28 to 97.72
5	98.76	0.62 to 99.38
5.152	99	0.50 to 99.50
6	99.73	0.14 to 99.86
6.582	99.9	0.05 to 99.95

If a sample is unimodal, without skewness, the size distribution generally plots, as is well known, as a straight line on probability paper. Where sizes are identified in terms of phi, arithmetic probability paper is satisfactory. For such a sample, $D_2 = D_{2.56} \neq D_{3.29}$. Furthermore, any other spread, or range, can be used, provided the difference between the two selected percentiles is divided by the total number of standard deviations involved.

In actual practice, few size distributions are perfectly symmetrical. In sediments, the asymmetry is commonly limited to a relatively small portion of one of the tails, that is, 6 percent. For such a sample,

[1] Manuscript received December 10, 1957.
[2] They can be transformed by use of $D_k = \log_2 So^{1.48}$.

$D_2 = D_{2.56} \neq D_{3.29}$. Such comparisons can be made only if the procedure for calculating the various deviation measures is standardized. Furthermore, variable parameters, such as those given above, permit an indication of an additional attribute, without adding new terminology or symbolism: the extent to which the indicated sorting covers, or represents, the entire distribution curve. A sample for which $D_2 = D_{2.56} = D_{3.29} = D_6$ is obviously more completely described by the last (D_6) than by the first (D_2).

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 2, PP. 205–208
FIGS. 1–2, JUNE, 1958

SYNGENETIC CHERT IN THE MIDDLE ORDOVICIAN HARDY CREEK LIMESTONE OF SOUTHWEST VIRGINIA[1]

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ABSTRACT

Chert nodules centered in desiccation polygons were observed in outcrops of the Hardy Creek Limestone of southwest Virginia. An apparent correlation exists between the shape and spacing of the chert nodules and the arrangement and spacing of the desiccation cracks. This relationship suggests that the chert was present as discrete nodules before the lime mud was subjected to desiccation.

INTRODUCTION

In mapping the geology of the northwest part of the Duffield Quadrangle, southwest Virginia (fig. 1), the writer and Ralph L. Miller observed several occurrences of chert nodules centered in desiccation polygons in outcrops of the Hardy Creek Limestone of Middle Ordovician age. One of the best examples is shown in figure 2.

The Hardy Creek Limestone, which has an average thickness of 130 feet, is divisible into lower and upper limestone units separated by a middle argillaceous limestone unit. Both the lower and upper units are composed of calcilutite in beds 2 to 6 in thick. These beds, commonly laminated, have occasional desiccation-cracked surfaces and contain some intraformational conglomerate. Chert, although not abundant, occurs as discrete nodules in persistent zones in both the lower and upper units. These nodules tend to be ellipsoidal and have remarkably smooth and featureless exteriors. They are of different sizes, but generally are not more than 6 in long, about 4 in wide, and approximately 2 in thick. In cross section the nodules taper slightly toward the edges and tend to be either biconvex or planoconvex. Megascopically, the chert is uniformly cryptocrystalline and is dark gray to olive black. Contacts between the chert nodules and the surrounding limestone are sharp. Jointing in the chert is prominent and closely spaced; as a consequence, the chert commonly weathers to angular fragments. Many of these joints extend through the chert into the limestone.

[1] Publication authorized by the Director, U. S. Geological Survey. Manuscript received December 15, 1957.

RELATIONSHIP OF THE CHERT NODULES TO THE DESICCATION CRACKS

In a small area near the head of Wallen Creek, chert nodules surrounded by desiccation cracks occur in outcrops of the upper limestone unit of the Hardy Creek Limestone (fig. 2A). These desiccation cracks are considered to be a primary feature of the rock. The depth to which these cracks extend into the limestone is obscured by crack-filling material that is nearly identical in lithology to the undisturbed limestone, but the cracks seem to merge into the main body of the limestone not more than an inch below the surface.

The fact that the chert nodules are centered in desiccation polygons strongly suggests a syngenetic origin for the chert (fig. 2). A chance relationship does not seem likely because in three separate outcrops, which are 50 to 100 feet apart, the nodules are centered within enclosing cracks.

Even though the relationship of the desiccation cracks and the nodules tends to establish the time of chert formation as not later than burial of the desiccation surface, the exact time of chert formation is uncertain. The silica and the lime mud could have been deposited either contemporaneously or penecontemporaneously. Contemporaneous deposition, as used in this paper, refers to deposition of the silica before the lime mud was subjected to desiccation; penecontemporaneous deposition refers to silica deposition after the lime mud was desiccated.

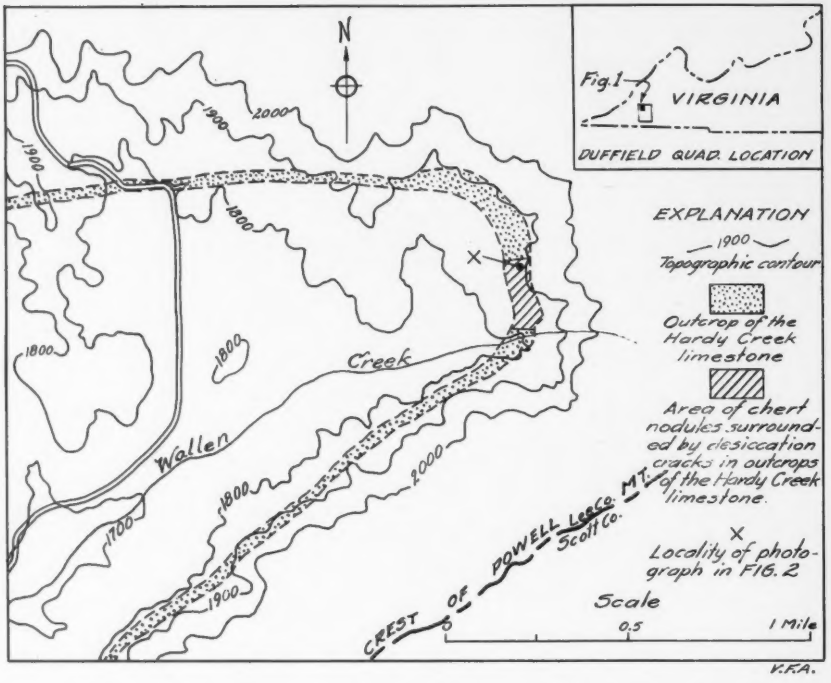


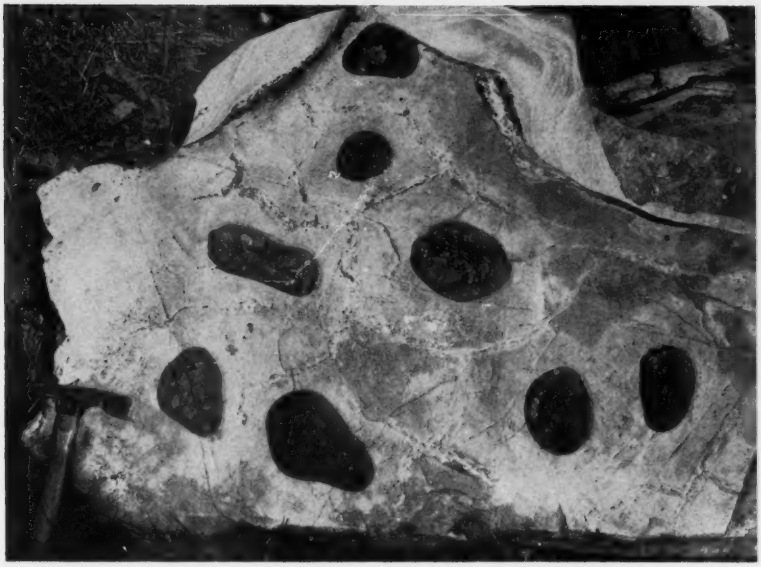
FIG. 1.—Area of chert nodules surrounded by desiccation cracks in outcrops of the Hardy Creek Limestone in the extreme northwest part of the Duffield 7½ minute Quadrangle, southwest Virginia.

CONTEMPORANEOUS DEPOSITION

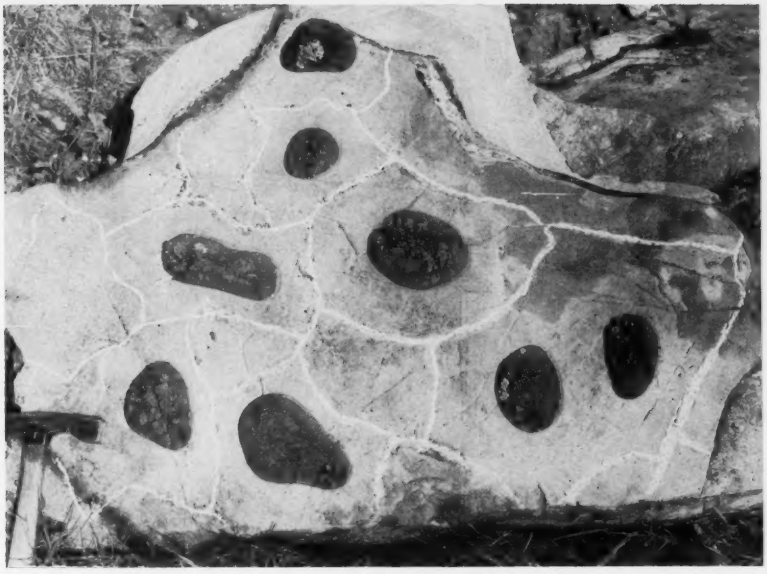
Inasmuch as the limestone of the Hardy Creek is composed of clay- or silt-size calcite particles, it is assumed that the original material was deposited as a calcareous mud. Because of its probable homogeneity, this calcareous mud on undergoing desiccation conceivably could give up water rather evenly over its entire exposed surface. If silica masses were present when the calcareous mud was undergoing desiccation, they would tend to impede desiccation in areas immediately beneath them and differential desiccation could result. Because desiccation cracks tend to develop in places where the horizontal stresses exceed the cohesive force of the calcareous mud, the points of cracking could occur anywhere outside the periphery of chert masses.

Apparently the size, shape, and spacing of the individual chert nodules affected the spacing and arrangment of at least some of the desiccation cracks. In the left center of figure 2A and B an elongate chert nodule clearly shows the desiccation cracks paralleling its length, and in the right center a large circular nodule seems to have caused the cracks to assume a nearly circular plan. Ralph L. Miller reminded the writer that in areas where we have observed calcilutites without chert nodules but with desiccated surfaces, the individual polygons are fairly uniform in size and shape. This, of course, suggests that the irregular-shaped polygons in figure 2 are not due to the lack of homogeneity in the calcareous mud, but to the influence exerted by the nodules.

Simple experiments and field observation of present-day desiccating surfaces by the writer have suggested that when a solid object of moderate size is present on a desiccating surface of relatively pure c'ay,



A



B

FIG. 2.—Photographs of desiccation cracks surrounding chert nodules in the Hardy Creek Limestone. A, shows in natural contrast the relationship of the desiccation cracks to the chert nodules. B, same view but desiccation cracks chalked for better contrast.

the cracks tend to develop near the periphery of the object. As shown in figure 2, the desiccation cracks in the Hardy Creek Limestone are not so located. Perhaps the location of the cracks away from the periphery of the chert nodules was controlled by the permeability of the calcareous mud. If there was a high degree of permeability, water could migrate outward by capillary action from beneath the chert masses; however, the effect of capillary migration of water would probably depend on the rate of desiccation. If the calcareous mud was drying out rather rapidly, not allowing enough time for capillary migration to replenish the supply of water, the cracks might be near the chert nodules. Conversely, if the rate of desiccation was slow enough to allow capillary migration to replenish the water being evaporated near the chert nodules, the cracks could be away from the periphery of the nodules.

Another possible explanation of the location of the desiccation cracks at some distance from the chert nodules is based on the assumption that the nodules, because they have weight, would probably exert enough force to cause a small basinlike depression on the surface of the calcareous mud immediately surrounding the nodules. Even though these depressions would be small, they could, upon exposure to the surface, contain enough water to affect the rate of desiccation near the periphery of a nodule with the result that the desiccation cracks would form some distance away from the nodule.

PENECONTEMPORANEOUS DEPOSITION

The chert nodules could have formed before the final burial of the desiccated surface, but after deposition and desiccation of the limestone. Surface irregularities of the individual polygons could have been the causative factor in determining the position of the chert nodules in relation to the desiccation cracks. During desiccation of the limestone the individual polygons as they formed may have cupped slightly upward forming small catchment basins. This slightly cupped surface, when covered by water, conceivably could trap later deposited silica gel. A major objection to this hypothesis is the fact that chert does not fill the cracks, even though the cracked areas formed excellent places where at least some chert could have accumulated.

CONCLUSIONS

A syngenetic origin for the chert in the upper limestone unit of the Hardy Creek Limestone is strongly suggested by the definite relationship shown between the shape and spacing of the chert nodules and the arrangement and spacing of at least some of the desiccation cracks. This influence exerted by the nodules in controlling the placement of the cracks lends support to the supposition that the chert was present before the lime mud was desiccated.

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PRELIMINARY OBSERVATIONS ON CHEMICAL DATA FROM SOME BRITISH UPPER CARBONIFEROUS SHALES[1]

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ABSTRACT

Analyses of shales from palaeontologically well-defined marine and non-marine horizons show that the recognition of past environments of deposition from the chemistry alone is probably a doubtful process.

As part of a wider investigation of some Upper Carboniferous sediments in northern England (Greensmith 1956, 1957) a whole series of shales have been recently chemically analysed. This contributory information towards gaining a full insight into the nature of the sediments has still to be studied in detail, but a few preliminary, and thus necessarily tentative, observations can be made.

The two most interesting analyses from the comparative point of view are probably those of fresh shaley material selected from a definite marine and non-marine horizon exposed in a 900 foot core at Smeekley Wood in northern Derbyshire. The interest evolves from the fact that their chemical differences appear to have no genetic significance (table 1). In each case, as a mineralogical check, thin-sections were made.

The marine horizon, characterized by the presence of the goniatite *Gastrioceras subcrenatum* C. Schmidt, consists of a fine-grained, dark grey and highly carbonaceous shale with abundant shell fragments preserved in coarse calcite and dolomite. The shells account for the relatively high CaO, MgO, and CO_2 percentages recorded in the analysis. The high sulphur content is caused by the presence of pyrite which seems to be authigenic and may have formed under the conditions envisaged by Rubey (1930). He suggested that the most favourable circumstances for the formation of pyrite involved a rapid accumulation and burial of carbonaceous matter. The carbonaceous matter slowly breaks down and pyrite forms in the putrefying ooze, any calcium carbonate meanwhile being little affected.

In contrast, the medium grey shale from the non-marine horizon and characterized by *Carbonicola spp.*, is medium-grained with angular quartz grains and much less carbonaceous matter. The very low pyrite content may be genetically related to this low percentage of carbonaceous material. Although some of the CO_2 is bound up in the calcitic and dolomitic shell fragments, most is attached to the FeO in the form of chalybite which is abundantly distributed throughout.

Consideration of these two full analyses and the thin-section petrography would appear to suggest useful criteria for the

TABLE 1.—*Full chemical analyses of shales, Smeekley, Derbyshire*

	(1)	(2)
SiO_2	29.82	43.05
TiO_2	0.48	0.78
Al_2O_3	12.16	18.52
FeO	7.12	13.16
Fe_2O_3	1.73	0.68
MnO	0.31	0.32
CaO	10.38	1.46
MgO	5.60	3.34
K_2O	1.74	1.43
Na_2O	0.34	0.66
H_2O +	4.06	6.03
H_2O −	2.08	1.05
CO_2	10.57	6.18
C and Hydrocarbons	10.93	2.72
P_2O_5	0.92	0.33
SrO	0.11	0.08
S	2.44	0.12
	100.79	99.91
Less 0 for S	0.61	0.03

(1) Pot Clay marine band. Junction between Millstone Grit and Coal Measures. Analyst, W. H. Herdsman (New Series).

(2) Non-marine mussel band. Millstone Grit, approximately 25 feet below the Pot Clay marine band. Analyst, W. H. Herdsman (New Series).

[1] Manuscript received December 17, 1957.

TABLE 2.—*Partial chemical and mineralogical analyses of shales, Smeekley, Derbyshire*

	FeS_2 (Pyrite)	Organic C
Pot Clay Marine Band	4.50%	10.93%
Cumbriense M.B. (Millstone Grit)	2.97	6.27
Cancellatum M.B. (Millstone Grit)	9.70	3.09
Lingula Shale (Coal Measures)	14.50	5.21
Non-marine Shale (Millstone Grit)	0.20	2.72

Analysts, J. T. Greensmith and W. H. Herdsman.

distinction between marine and non-marine shales, a step considered desirable by Trueman (1946) and all subsequent Carboniferous workers, stratigraphers, and sedimentologists alike. For instance, the differences in the amount of Fe and S, which can be mineralogically linked with pyrite and chalybite, clearly indicates environmental modifications. Similarly, the organic C, and thus carbonaceous matter, differences may be significant. Indeed, as already suggested, the actual quantity of pyrite present within these shales is likely to be closely associated with the relative amount of carbonaceous matter present. However, additional analyses of other shales indicate that this probable linkage is independent of a marine or non-marine origin. More analyses should substantiate this view-point. These analyses (table 2) also show that the chemical and mineralogical relationship of pyrite to organic (carbonaceous) matter is far from being a simple one. Possibly this may be partially due to variation in the nature of the carbonaceous material, some being more prone to breakdown into organic acid complexes than others, but confirmation is impossible since the material has not yet been adequately separated and analysed.

Both Trueman (1954) and Dunham (in Edwards, Stubblefield, and Dunham, 1948) have recorded the presence of abundant pyrite at non-marine horizons in Upper Carboniferous shales in Britain. Moreover, Dunham has suggested that the reducing conditions suitable for the formation of the pyrite were probably created by decaying organic matter, and also believed that similar conditions probably caused the precipitation of chalybite which, he noted, is abundant at many marine and non-marine horizons.

Thus it seems to be more probable, as additional data accumulate, that the presence of chalybite, carbonaceous matter, and pyrite is not uniquely diagnostic of environment, at least in Upper Carboniferous times. In other words, the fauna still remain the most reliable indicators of conditions at the time of deposition. On the whole this is rather unfortunate, since so many of the shaley beds seem to be devoid of faunal content.

What may be more illuminating eventually are the clay minerals. However, Dr. G. Nagelschmidt kindly analysed by X-ray techniques both the Pot Clay marine band and the mussel band (table 1) and recorded in each roughly equal amounts of illite (variety unspecified) kaolinite (in the specific sense). A closer investigation into the nature of the illitic clay minerals may be useful.

In this preliminary work outlined above the cost of all the analyses was borne by the Department of Geology, University of Sheffield.

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FIGS. 1–11, JUNE, 1958

DIFFERENTIATION OF BEACH, DUNE, AND AEOLIAN FLAT ENVIRONMENTS BY SIZE ANALYSIS, MUSTANG ISLAND, TEXAS[1]

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ABSTRACT

Mustang Island is a 16-mile-long barrier island on the south Texas Gulf coast. Sediments consist of very well sorted fine sands (mean size 2.82ϕ, average $\sigma_1 = 0.29\phi$), and show exceedingly uniform properties lengthwise of the island. Beach, dune, and aeolian flat environments can be readily distinguished by size analysis. The best means of differentiating them is by plotting skewness versus kurtosis inasmuch as the geologic processes at work have their greatest effect on the tails of the size distribution. Beach sands form normal curves, dune sands are positively skewed but still mesokurtic, and aeolian flat sands are positively skewed and leptokurtic. Sands from the beach are more poorly sorted than those from the other two environments. These differences are extremely significant with P values between .0002 and .0000001. To explain these changes, it is proposed that as sand travels from the beach to the dunes, the coarse end of the parent normal population lags behind, rendering the size curves better sorted and also positively skewed. The aeolian flats are believed to be subject to infiltration of silt from the atmosphere; this imparts a "tail" of fines, registering a marked increase in kurtosis.

INTRODUCTION

Mustang Island, situated on the South Texas coast, separates Corpus Christi Bay from the Gulf of Mexico (fig. 1). It is one of a continuous chain of sand beaches and barrier islands that extend along the western Gulf coast from Louisiana to southern Mexico. Mustang Island trends south-southwest and is approximately 16 miles long and 1 to 3 miles wide; on the northeast it is separated from St. Joseph Island by Aransas Pass, and on the southwest it now merges without break into Padre Island, the pass that formerly existed between them having been closed by storms in 1950.

The nearest weather station is at Corpus Christi where the average annual rainfall is 26.5 inches with a mean annual temperature of 71.0°F. The Köppen classification of the climate is BShn′, signifying a hot, semiarid steppe climate with high humidity but no great amount of fog. Normally, the wind blows inland from the southeast at a mean speed of 10 to 12 knots; however, at intervals during the winter strong northerly winds prevail for periods of several days. Waves are usually 1 to 3 ft high, and the slope offshore from the island is very gentle; tides measure only about 2 ft. Hurricanes occasionally form during early fall, and strike any particular point along the Texas coast about once in 25 years.

Except for the small fishing and tourist town of Port Aransas at the north end, the island is sparsely occupied and given over to cattle. A road connecting Port Aransas with the Corpus Christi causeway extends the length of the island, and it is also possible to drive a car along the Gulf beach the full distance; thus surf bathing and fishing is a common activity along the island.

Mustang Island was selected as a testing ground to determine if there exists a statistically significant difference in grain size properties between sands of the various environments on a barrier island. Beach, dune, and aeolian flat environments are well developed here, and it was hoped that a study of the deposits therein might serve as an aid in distinguishing similar environments in ancient sediments. Further, a study of the differences between the sands should aid in understanding the geologic processes at work in the area.

Skewness and kurtosis have been for so many years recorded in a merely perfunctory way (their main purpose seemingly being to beef up tables of data) that there has been considerable question as to whether they had any practical value. Consequently another purpose of this study was to determine if these obscure measures had any utility on Mustang Island. They have met the challenge well; it turns out that these two properties are the very ones that best identify the environments studied!

[1] Manuscript received January 23, 1958.

PHYSIOGRAPHY

All three environments are normally sharply distinguished and extend in narrow strips down the length of the island with little change in width. The Gulf beach averages about 200 ft wide, but may be entirely submerged during very high storm-induced tides. The front part of the beach slopes at an angle of a few degrees and is littered with shell debris; it is separated from the main part of the beach by a sharp break in slope (fig. 2). The main part of the beach is very flat and contains almost no shells (sieving shows less than 0.1 percent of the sample). At the back of the beach is a 150-foot strip of low, overlapping dunes, only about 5 ft high and sparsely vegetated. These grade into a 350-ft wide belt of larger dunes, as much as 20 to 40 ft high and completely stabilized by vegetation, chiefly

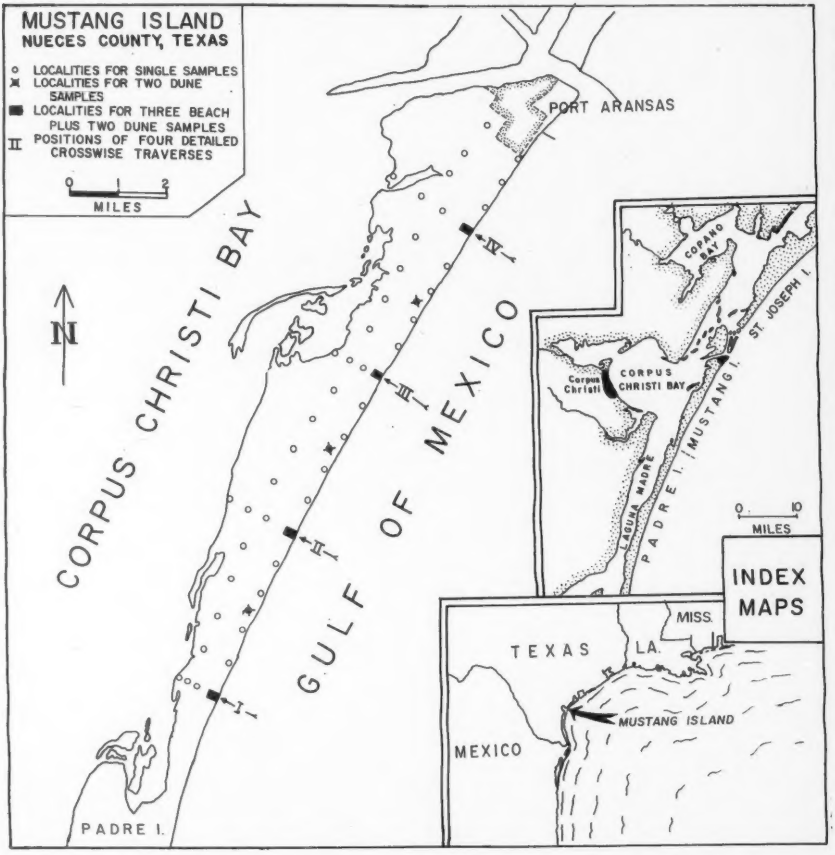

FIG. 1.—Mustang Island, Texas, showing sampling sites. Four traverses were made crosswise of the island (designated I, II, III, and IV). Along each of these crosswise traverses, three beach and two dune samples were taken (position shown by the black block; for details of sample location see fig. 2); and three aeolian flat samples were taken (shown by open circles). Two detailed traverses were made lengthwise of the island, one down the middle of the beach and the other down the aeolian flat (all shown by open circles). Furthermore, midway between each of the four crosswise traverses, a pair of dune samples was taken (shown by the crossed circle symbol).

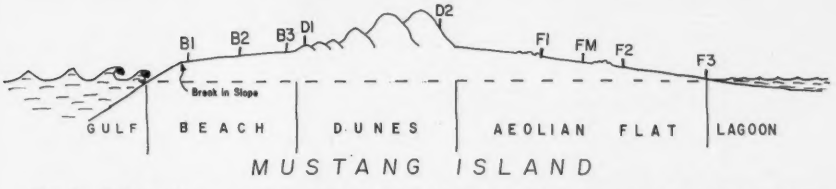

FIG. 2.—Schematic cross-section of Mustang Island showing detailed location of samples. Distances greatly distorted; the aeolian flat is 1 to 3 miles wide while the beach and dune belt combined average only 500 to 1000 feet wide. The four crosswise traverses consisted of three beach samples (B1, B2, B3); two dune samples, one at each edge of the dune belt (D1, D2); and three samples spaced equally across the aeolian flat (F1, F2, F3). One lengthwise traverse was taken down the mid-beach, at the position of B2; the other lengthwise traverse was down the middle of the aeolian flat, at the position of FM. Additional dune samples were taken at D1 and D2.

sea-purslane and sea-oats. The large dunes form one to three rows parallel with the coast. At several places blowout tongues of bare sand, forming small barchan-type migrating dunes, extend nearly halfway across the island.

The aeolian flat occupies by far the greatest area on the island, beginning abruptly behind the dunes and occupying the remaining 1 to 3 mile width of the island. The term "aeolian flat" is not meant to imply that this large physiographic feature necessarily originated by aeolian action since it may have been formed by washovers or other means. The term merely signifies that the present-day surface skin of sediments over this flat area is now being influenced by wind action. The flat has an elevation of 5 ft or less and is normally smooth and featureless and extensively vegetated with marsh or Bermuda grass. On it there are occasional patches of low vegetated dunes. Low parts of the flat are sometimes flooded at high tide from the lagoon side. Small numbers of cattle graze on this part of the island. The aeolian flat merges with an imperceptively gentle slope into the lagoon beach, and the water line is extremely irregular with many small peninsulas and islands. The lagoon beach is so poorly differentiated from the aeolian flat that they are considered together in the analytical work. Behind Mustang Island is Corpus Christi Bay, floored with clay or sandy clay and averaging only 12 ft deep.

PROCEDURE

Samples were collected using a grid system. Four crosswise traverses, each consisting of eight samples, were spaced at intervals of 4 miles along the island (fig. 1). On the crosswise traverses, the following samples were taken, designated as shown in figure 2: (1) main beach 3 ft inland from the slope break, B1; (2) middle of the main beach, B2; (3) back of the main beach 5–10 ft in front of the first low dune, B3; (4) halfway up the windward side of the first low dune, D1; (5) halfway down the leeward side of the last large dune, D2; (6) one-third of the way across the aeolian flat, F1; (7) two-thirds of the way across the flat, F2; and (8) at the back of the aeolian flat just above the lagoon shoreline, F3. Two traverses were also taken lengthwise of the island, one down the middle of the main beach and one along the midline of the aeolian flat; these samples were spaced 0.8 miles apart. Two additional dune samples were taken between each of the crosswise traverses. In all, 31 beach samples, 14 dune samples, and 31 aeolian flat samples were analyzed on the grid. To avoid lag sediments, the top inch layer of sand was removed and the sample analyzed was a one inch cube buried an inch below the surface.

The samples were de-salted, disaggregated, and sieved for 15 minutes with a Ro-Tap machine using the following 8-in diameter screens: 2.0ϕ, 2.5ϕ, 2.75ϕ, 3.0ϕ, 3.25ϕ, 3.5ϕ, 4.0ϕ, 4.5ϕ, and pan. Fractions were examined and corrected for aggregates (usually there were none) and weighed to 0.01 gm, but fractions smaller than one gm were weighed to 0.001 gm. Because of the superb sorting of the sand, it was found that if samples weighing 50–60 gm were sieved, the measured phi diameter was consistently 0.05ϕ coarser than when replicate samples of 30–35 gm were used; this is

TABLE 1.—*Distribution of size parameters*

A. DISTRIBUTION OF MEAN SIZE (M_z) VALUES

Environment	Mean of M_z Values	Standard Deviation of M_z Values	Central Two-Thirds	Extreme M_z Values	Character of Distribution
Beach	2.82ϕ (0.142 mm)	0.070ϕ	2.75ϕ–2.89ϕ	2.65ϕ–3.00ϕ	near-normal
Dunes	2.86ϕ (0.138 mm)	0.094ϕ	2.77ϕ–2.95ϕ	2.69ϕ–2.98ϕ	strongly bimodal, modes 2.80ϕ and 2.96ϕ
Flats	2.83ϕ (0.141 mm)	0.045ϕ	2.78ϕ–2.87ϕ	2.75ϕ–2.89ϕ[1]	near-normal

[1] One aberrant sample from the edge of the lagoon on the south side of the island has $M_z = 2.27\phi$, but this is so far beyond the rest of the samples that it is not considered.

Results of t tests:

Beach versus Dunes, P = .10 (difference dubious).
Beach versus Flats, P = .42 (no difference).
Dunes versus Flats, P = .23 (no difference).

B. DISTRIBUTION OF GRAPHIC STANDARD DEVIATION (σ_I) VALUES

Environment	Mean of σ_I Values	Standard Deviation of σ_I Values	Central Two-Thirds	Extreme σ_I Values	Character of Distribution
Beach	0.309ϕ	0.021ϕ	0.29ϕ–0.33ϕ	0.26ϕ–0.40ϕ	near-normal
Dunes	0.273ϕ	0.026ϕ	0.25ϕ–0.30ϕ	0.22ϕ–0.32ϕ	near-normal
Flats	0.286ϕ	0.023ϕ	0.26ϕ–0.31ϕ	0.25ϕ–0.40ϕ	near-normal

Results of t tests:

Beach versus Dunes, P = .0001 (extremely significant).
Beach versus Flats, P = .0002 (extremely significant).
Dunes versus Flats, P = .07 (difference dubious).

C. DISTRIBUTION OF SKEWNESS (Sk_I) VALUES

Environment	Mean of Sk_I Values	Standard Deviation of Sk_I Values	Central Two-Thirds	Extreme Sk_I Values	Character of Distribution
Beach	+.03	.06	−.03 to +.09	−.16 to +.12	Slightly bimodal, modes −.02, +.08
Dunes	+.14	.08	+.06 to +.22	+.03 to +.26	Slightly bimodal, modes +.06 and +.21
Flats	+.17	.07	+.10 to +.24	+.04 to +.26	near-normal

Results of t tests:

Beach versus Dunes, P = .00001 (extremely significant).
Beach versus Flats, P = .0000001 (extremely significant).
Dunes versus Flats, P = .22 (no difference).

TABLE 1.—*Continued*

D. DISTRIBUTION OF KURTOSIS (K_G') VALUES

Environment	Mean of K_G' Values	Standard Deviation of K_G' Values	Central Two-Thirds	Extreme K_G' Values	Character of Distribution
Beach	.522 (1.09)	.019	.503–.541 (1.01–1.18)	.492–.444 (0.97–1.25)	near-normal
Dunes	.517 (1.07)	.020	.497–.537 (0.99–1.16)	.484–.546 (0.94–1.20)	near-normal
Flats	.546 (1.20)	.024	.522–.570 (1.09–1.33)	.492–.592 (0.97–1.45)	near-normal

Figures in parentheses give equivalent K_G values.

Results of t tests:

Beach versus Dunes, P = .45 (no difference).
Beach versus Flats, P = .0001 (extremely significant).
Dunes versus Flats, P = .0002 (extremely significant).

because of the tendency of the sand to jam up on those screens near the mode. Hence the total sample weight was rigorously maintained at between 30 and 35 gm. Results were plotted as cumulative curves on probability paper using the phi scale (Krumbein, 1934).

Statistical parameters used in describing the grain-size properties of the sand are those proposed by Folk and Ward (1957). These parameters are necessitated because the main differences between Mustang Island samples lie in the far extremes of the distribution, a region not covered by more conventional measures such as Trask's *So* (Trask, 1932), the quartile deviation (Krumbein and Pettijohn, 1938, p. 230) or Inman's (1952) phi deviation measure.

In order to evaluate experimental error—that is, how accurate are the reported values of the various parameters—five samples were selected and each was split into two subsamples. The ten subsamples were given meaningless code numbers by a colleague and returned for sieving and computation. Then the statistical parameters obtained from the two splits of the same sample were compared. For each parameter, the value of the root-mean-square (rms) deviation was computed. The following rms deviations were obtained: Mean (M_z), $\pm 0.008\phi$; graphic standard deviation (σ_I), $\pm 0.007\phi$; skewness (Sk_I), ± 0.019; transformed kurtosis (K_G'), ± 0.0051. This means that if a sample is sieved repeatedly, two-thirds of the analyses will fall within the range of the true value plus or minus one rms deviation (for example, if a sample with a true M_z of 2.850ϕ and true Sk_I of $+.12$ is sieved 100 times, then 68 of the sievings will yield M_z values between 2.842 and 2.858, and Sk_I values between $+.10$ and $+.14$).

MINERALOGY, GRAIN SHAPE, AND SOURCE OF THE SAND

The sand grains are well sorted but not rounded; consequently the sand is classified as a texturally mature subarkose (Folk, 1954). A count of 540 grains with the petrographic microscope showed 9 percent feldspar (about half orthocase and half microcline), 2 percent chert, 3 percent composite metamorphic quartz and 86 percent common quartz. Inspection of sieved fractions reveals that the samples contain less than 0.1 percent of finely broken shell fragments, nearly all in the coarsest sizes. Bullard (1942) found that the heavy minerals of Mustang Island consist of almost half opaque grains; the chief non-opaque mineral is green hornblende with zircon next and smaller amounts of staurolite, epidote, garnet, and others. Bullard believed that the sand on Mustang Island was drifted southwestward by longshore currents from the Colorado River which reaches the coast about 100 miles to the northeast. This source is indicated by the fact that the Colorado is the only river in Texas that carries large amounts of green hornblende. An unpublished study by Norman Bishop and Charles Mankin, The University of Texas, has revealed that sands in the lower

part of the Colorado River carry 5 to 10 percent potash feldspar; thus both light minerals and heavy minerals of Mustang Island indicate derivation from Colorado River detritus.

The grains average subangular (Powers, 1953) but range from very angular to round; it appears that very nearly all the roundness is inherited. Most of the grains are dull-surfaced, and on only a very few is there any sign of incipient edge-rounding of the sharpest corners. Sand from the lower Colorado River shows a very similar assemblage of grain shapes and surface features. Apparently these grains are too fine (2.5ϕ to 3.2ϕ) for beach or dune abrasion to have much effect in modifying the surface features or roundness of individual grains, and these properties are simply inherited from the fluvial assemblage.

FREQUENCY DISTRIBUTION OF VALUES OF MEAN SIZE, STANDARD DEVIATION, SKEWNESS AND KURTOSIS FOR THREE ENVIRONMENTS

For each of the four grain size parameters, smoothed frequency curves have been constructed to show the differences between sands from the beach, dunes, and an aeolian flat. These enable one to compare the range of sorting, skewness, etc. encountered in each environment and also depict the degree of overlap. The raw data from which these frequency distributions are compiled may be inspected in the two scatter plots, figures 8 and 9; data are also shown in table 1.

Mean size (M_z) is determined by the formula

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

where $\phi 16$ stands for the phi diameter at the 16th percentile of the distribution, etc. Mean grain size of all the environments is very similar (fig. 3) with all of the samples being classified as fine sand, close to the boundary of very fine sand. The beach sands show a nearly normal distribution of mean size, averaging 2.82ϕ (0.142 mm) with a standard deviation of 0.070ϕ. This indicates that the central two-thirds of the samples have mean sizes ranging between 2.75ϕ and 2.89ϕ (0.135 to 0.149 mm). The distribution of mean size for the dune sands

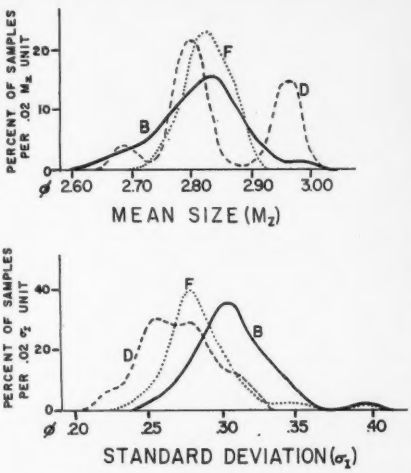

FIG. 3. Frequency distribution of mean size values and graphic standard deviation values for all samples from all environments. Beach, solid line (B); dune, dashed line (D); aeolian flat, dotted line (F). The frequency curves are read as follows: the "beach" curve attains a frequency value of 13 percent at a mean size of 2.80ϕ. This means that 13 percent of the beach samples analyzed had mean sizes between 2.79ϕ and 2.81ϕ (i.e. within the 0.02ϕ interval centered on the specified phi diameter).

In mean size, there is a complete overlap between the environments, with all the samples being classed as fine sand (grand mean 2.83ϕ). The island-wide uniformity in mean size is very striking. Considering the graphic standard deviation, almost all the samples are classed as very well sorted, but among these the beach samples show poorest sorting (average σ_I about .31ϕ). Frequency distributions of sorting values are nearly normal.

is bimodal with most of the M_z values at about 2.80ϕ and another smaller cluster at about 2.96ϕ. The average dune M_z is 2.86ϕ (0.138 mm) with a standard deviation of 0.094ϕ. The aeolian flat samples have normally distributed M_z values about a mean of 2.83ϕ (0.141 mm) with a standard deviation of 0.045ϕ. The aeolian flat samples are almost unbelievably uniform in mean size; the *extreme* values among the 31 samples sieved are 2.75ϕ and 2.89ϕ, except for one completely aberrant sample at 2.27ϕ, which is omitted from all calculations because it is over 8 standard deviations from the mean.

Are the dune sands really finer than the

beach sands as it appears from the above data? To determine the significance of the difference in mean size between the environments Student's t test (Brownlee, 1948) was applied. This test states the probability (P) that differences in means are due to chance sampling. For example, if P equals .10, it means that there is a 10 percent chance that the apparent differences between two sets of samples are merely accidental. Most workers adopt the convention that P must be less than .05 in order for differences to be considered as significant. For this set of samples P = .10 for beach versus dunes, P = .23 for dunes versus aeolian flat, and P = .42 for beach versus aeolian flat. Thus, our analysis has failed to reveal any significant difference in mean grain size between the environments.

The grand mean (unweighted) for the sediments of the island is 2.832ϕ (0.140 mm) with a standard deviation of 0.070ϕ which means that two-thirds of the samples have mean sizes between 2.76ϕ and 2.90ϕ (0.134 to 0.148 mm). The remarkable similarity between all samples in average grain size indicates a very peculiar set of conditions. Apparently the source supplying sand to Mustang Island contributes only a very limited range of sizes and the environmental processes presently working on the sands are able to effect an extreme degree of homogenization.

Inclusive graphic standard deviation (σ_I) is a measure of sorting, found by the formula

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}.$$

If the grain size distribution is Gaussian-normal, 68 percent of the sample will lie within the range of $M_z \pm \sigma_I$. Graphic standard deviation values of all the environments on Mustang Island are close, with almost all the samples being classed as very well sorted (defined as σ_I under 0.35ϕ; Folk and Ward, 1957, p. 13). All of the areas show a nearly normal frequency distribution of graphic standard deviation values (fig. 3). The beach sands are slightly more poorly sorted, having an average σ_I of 0.309ϕ with a standard deviation of 0.021ϕ. This means that the central two-thirds of the beach samples have σ_I between 0.288ϕ and 0.330ϕ. The dune sands have the best sorting with an average σ_I of 0.273ϕ and a standard deviation of 0.026ϕ. The aeolian flat samples are intermediate in sorting, having an average σ_I of 0.286ϕ with a standard deviation of 0.023ϕ.

By applying Student's t test to this set of samples it was determined that the probability of these differences being due to chance was only .0001 for the beach versus the dunes, .0002 for the beach versus the aeolian flat, and .07 for the dunes versus the aeolian flat. Thus the beach samples are very significantly more poorly sorted than the dune or aeolian flat samples, but the latter two environments have essentially similar sorting.

Skewness (Sk_I) measures the symmetry of the distribution by the formula

$$Sk_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}.$$

Symmetrical curves have $Sk_I = .00$, and as skewness becomes more extreme the value of Sk_I approaches a theoretical maximum of $+1.00$ or -1.00. There is considerable difference in skewness between the beach sediments and the dune and aeolian flat sediments, with most of the beach sediments having nearly symmetrical curves (fig. 4). The dune and aeolian flat samples, on the contrary, are positively skewed (having a tail of fine grains). The beach sediments show bimodality of Sk_I with modes coming at about -0.02 and $+0.08$; the negatively-skewed samples are those nearest the Gulf. The Sk_I distribution of the dunes is weakly bimodal with modes at $+0.06$ and $+0.22$. The aeolian flat samples have a more nearly normal Sk_I distribution, and the primary mode occurs at $+0.16$. Mean and standard deviation of skewness values for the samples from the various areas are as follows: beach $Sk_I = +0.028$ (near-symmetrical), σ 0.060; dunes $Sk_I = +0.139$ (fine skewed), σ 0.079; and aeolian flat $Sk_I = +0.169$ (fine skewed), σ 0.068. Not one of the 45 dune or aeolian flat samples has negative skewness, the smallest value for any sample being $+.03$.

By applying Student's t test, the differences in skewness are extremely significant; the probability of these differences being due to chance is P = .00001 for the beach versus dunes, P = .0000001 for the beach versus the aeolian flat, and P = .22 (non-

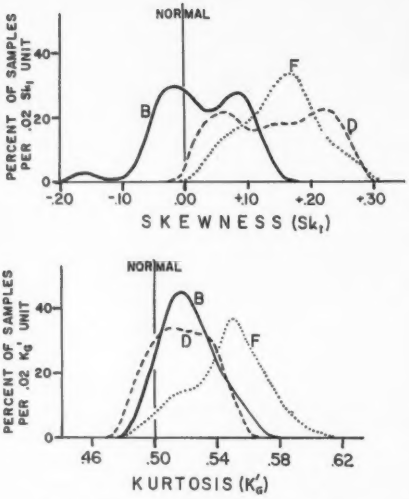

FIG. 4.—Frequency distributions of skewness values and kurtosis values for all environments. Beach, solid line (B); dune, dashed line (D); aeolian flat, dotted line (F). Beaches tend to give nearly symmetrical curves, while dune andaeolian flat samples both show pronounced positive skewness because of a tail of "fines." Considering kurtosis, beaches and dunes yield nearly normal (mesokurtic) curves while the aeolian flat samples are distinctly leptokurtic.

significant) for the dunes versus the aeolian flat. This shows that the dune and aeolian flat sediments are very significantly more fine-skewed than the beach sediments, because of a tail of fines to the right of the mode.

Kurtosis (K_G) measures the normality of a distribution by comparing the sorting in the central part of the curve with the sorting in the tails; if the curve is Gaussian-normal this ratio must be a constant value. The formula used here is

$$K_G = \frac{\phi 95 - \phi 5}{2.44 \times (\phi 75 - \phi 25)},$$

and with this formula normal curves (no matter what their overall sorting) have $K_G = 1.00$. A curve with kurtosis of 1.20 is leptokurtic (better sorted in the central part than the tails); the value signifies that, for a given degree of sorting in the central part of the distribution ($\phi 25$ to $\phi 75$), the spread between the tails ($\phi 5$ to $\phi 95$) is 1.20 times as great as it should be if the distribution were normal. For statistical purposes (t tests, computations of standard deviations, means, etc.) it is better if the normalized function

$$K_G' = \frac{K_G}{K_G + 1}$$

is used (Folk and Ward, 1957). In this transformation, normal curves have $K_G' = .50$, leptokurtic distributions have values above this and platykurtic, below this.

The beach and dune sediments are on the mesokurtic-leptokurtic borderline while the aeolian flat sediments are distinctly leptokurtic (fig. 4). The mean and standard deviation of the kurtosis values are as follows: beach $K_G' = .522$ (mesokurtic), $\sigma = 0.019$; dune $K_G' = .517$ (mesokurtic), $\sigma = 0.020$; and aeolian flat $K_G' = .546$ (leptokurtic), $\sigma = 0.024$. All of the kurtosis distribution curves are nearly normal. By applying Student's t test it was determined that the probability of these differences being due to chance was $P = .45$ (insignificant) for the beach versus dunes, $P = .0001$ for the beach versus aeolian flat, and $P = .0002$ for the dunes versus the aeolian flat. This means that the aeolian flat sediments are very significantly more leptokurtic than the dune and beach sediments.

SUMMARY

These results show that it is very easy to distinguish the three environments on Mustang Island by size analysis, despite the phenomenal uniformity of mean grain size. Because differences between samples exist almost entirely in the "tails" of the curves, skewness and kurtosis are the most valuable parameters to use in identifying the environments. Beach samples have normal curves; that is, they are near-symmetrical mesokurtic. Dune samples have curves that are fine-skewed but still mesokurtic. The aeolian flat samples have curves that are both fine-skewed and leptokurtic. The probability that these are chance differences ranges from 1 in 5000 to 1 in 10,000,000!

The following summary key may be used to distinguish the environments on Mustang Island:

Graphic Standard Deviation (σ_I)
0.21–0.26 probably dune
0.26–0.28 dune or aeolian flat
0.28–0.30 indeterminate
0.30–0.35 probably beach
Skewness (Sk_I)
−.20 to +.02 probably beach
+.02 to +.05 beach or dune
+.05 to +.13 indeterminate
+.13 to +.30 dune or aeolian flat
Kurtosis (K_G')
.47 to .53 beach or dune
.53 to .55 indeterminate
.55 to .61 probably aeolian flat

It is evident that the beach sediments are uniquely distinguished by their normality and relatively poor sorting, while the only way to tell dune sands from aeolian flat sands is by kurtosis.

VARIATION IN PARAMETERS LENGTHWISE OF THE ISLAND

In the preceding section we have shown that very significant differences emerge if one compares all the beach sand samples with all the dune or aeolian flat samples. Now it is desirable to investigate if, considering one environment, there is any sys-

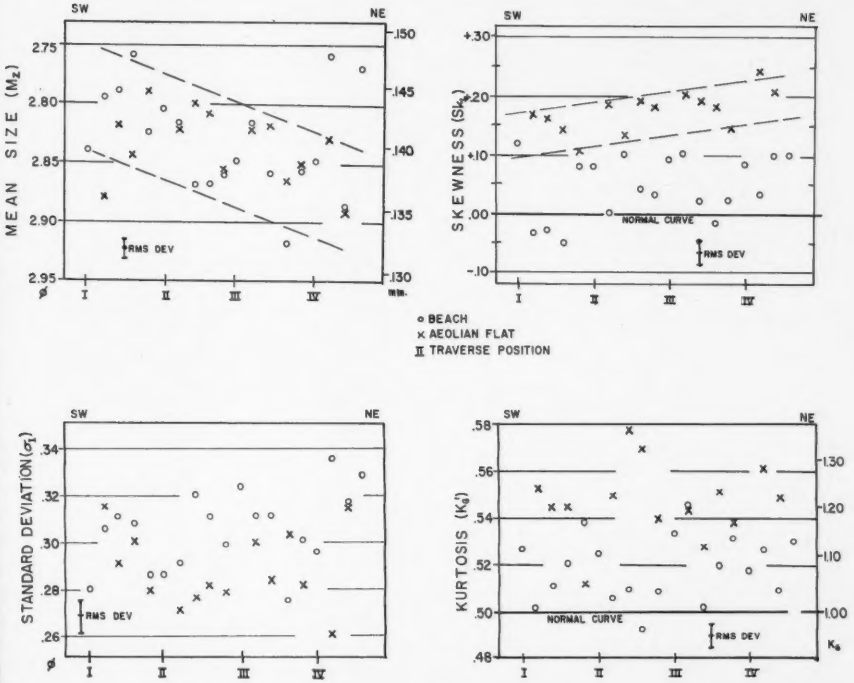

FIG. 5.—Variation in parameters lengthwise of the island. Roman numerals refer to positions of the crosswise traverses, from I at the southwest end to IV near the northeast end of the island. Beach samples shown by open circles, aeolian flat samples by crosses. Mean size shows a dubious tendency to coarsen slightly to the southwest, but there is great sample-to-sample fluctuation. There is no lengthwise change in standard deviation, but the beach samples are rather consistently more poorly sorted. In skewness there is a striking distinction beween beach samples and aeolian flat samples, the latter being in every case more positive-skewed than the beach sample in the corresponding geographic position. The aeolian flat samples appear to be more strongly skewed toward the northeast end of the island. Kurtosis shows no systematic change lengthwise of the island, but the aeolian flat samples are almost always more strongly leptokurtic. Brackets indicate the rms deviation (that is, probable experimental error) for each parameter: it is 68 percent certain that the true value of a parameter for a given sample lies within the bracketed range.

tematic change in parameters lengthwise of the island; that is, do the beach sands become better sorted to the southwest or is there a systematic decrease of kurtosis with distance in the aeolian flat? In studying this aspect, only the beach and aeolian flat samples that occurred along the lengthwise traverse were used—that is, only those taken from the middle of the beach and the middle of the flat (fig. 5). The dune samples were not used because they showed no hint of any lengthwise change. Even on the beach and aeolian flat there was very little systematic lengthwise change in the parameters; values fluctuated slightly from place to place in an apparently random fashion. Standard deviation and kurtosis showed no trend at all, the aeolian flats remaining consistently better sorted and more leptokurtic all the way down the island. In mean size (M_z), however, both beach and aeolian flat samples apparently coarsen from about 2.85ϕ at the northeast end to 2.80ϕ at the southwest end of the island. But there is so much scatter about this trend that the t test shows that the difference is probably not significant (comparing the M_z values of the northeast half of the island with those from the southwest gives $P = .10$; that is, there is one chance in ten that the apparent change is accidental). Skewness shows no systematic change down

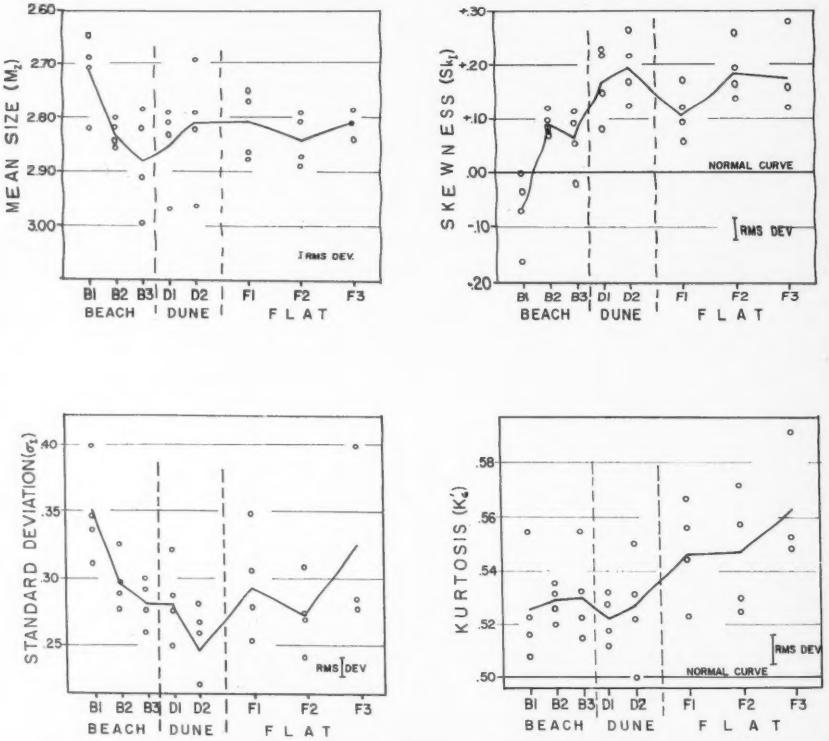

FIG. 6.—Detailed variation in parameters crosswise of the island. Sample location designations (B1, D2, etc. are as shown in fig. 2. Each small circle represents an analyzed sample from one of the four crosswise traverses; the solid line shows the mean value obtained by averaging the results from the four traverses. Mean size is coarsest near the Gulf but otherwise shows little change. Sorting is best at the rear of the dunes. Skewness and kurtosis both increase in passing from the Gulf toward the lagoon side of the island. Rms deviation brackets have the same significance as before.

the beach, but in the aeolian flat skewness apparently decreases from about +.20 at the northeast end to +.14 at the southwest end (figs, 5, 7). Comparing the northeast half of the aeolian flat with the southwest half, the t test gives P=.04, so that this may be a real change.

SIGNIFICANCE OF SAMPLE-TO-SAMPLE FLUCTUATION

Because values of the parameters fluctuate along the island (fig. 5) the question arises as to whether this variation is a gradual change between the sampling points or if the scale of fluctuation is much smaller than the sampling interval. For example, if the mean size at a hypothetical station A is 2.80ϕ and the mean size at station B is 2.90ϕ, then if one took four samples spaced at equal distances along a line between A and B, would the resulting values show a gradual transition (for example, 2.82ϕ, 2.84ϕ, 2.86ϕ, and 2.88ϕ) or a random fluctuation (for example, 2.88ϕ, 2.76ϕ, 2.89ϕ, and 2.82ϕ)? To check this, four additional equispaced samples were taken between one pair of regular grid sampling points on the beach and four more in a similar pattern on the aeolian flat. It was found that the parameters varied rapidly between grid sampling points, and, as a matter of fact, all size parameters fluctuated just as much between two successive sampling points on the original grid (0.8 mile apart) as they fluctuated the entire distance down the island (16 miles)! As a consequence the scale of fluctuation in parameters is less (perhaps much less) than 1000 feet.

VARIATIONS OF PARAMETERS ACROSS THE ENVIRONMENTS

Four crosswise traverses, spaced at intervals down the island, were taken. In these, as has been mentioned, three samples were taken from the beach (one nearest the water just above the break in slope, one in the middle, and one at the back of the beach near the dunes), two from the dunes (one next to the beach, the other next to the flat) and three spaced across the flats (figs. 1, 2). Heretofore all the samples from a particular major environment have been considered together; but it is found that even within one environment there is a gradual transverse change in that samples nearer the Gulf have different properties from those farther away. The parameters varied as shown in figure 6.

Mean Size.—The coarsest sediments analyzed were on the beach nearest the Gulf, for here $M_z = 2.71\phi$. The sediments became finer as the beach was crossed until $M_z = 2.88\phi$ on the backshore near the dunes. Mean size increased again in the dunes and then stayed nearly constant across the aeolian flat with $M_z = 2.82\phi$.

Standard Deviation.—Sorting on the beach near the Gulf was poorest with a standard deviation of 0.35ϕ. Sorting was much better on the back of the beach and in the first dunes with $\sigma_1 = 0.28\phi$ and continued to improve to 0.25ϕ on the lee side of the large dunes. Sorting became progressively poorer on the aeolian flat, reaching a value of 0.32ϕ near the lagoon.

Skewness.—On the beach nearest the Gulf the sediments were negatively skewed (−0.07), while at the back of the beach skewness changed markedly to +.08. The dune and aeolian flat samples were even more positively (fine) skewed, with skewness averaging +.15 to +.20. Figure 7 is a fence diagram which shows the variation in skewness both lengthwise and across the island.

Kurtosis.—Values of kurtosis were nearly constant at $K_G' = .525$–$.530$ for both the beach and dune sediments. Sands became abruptly more leptokurtic on the aeolian flat ($K_G' = .54$) and climbed to .56 for the sediments near the lagoon.

INTERRELATIONSHIP OF SIZE PARAMETERS

In order to see if the four size parameters on Mustang Island were interrelated, six scatter plots were made by coplotting each of the pairs of parameters (Folk and Ward, 1957). However, because of the extremely small range of mean size values (2.65ϕ to 3.00ϕ) and similarly small range of standard deviation values (0.22ϕ to 0.40ϕ), no plots using either of these two parameters resulted in any significant trends or correlations. An example of one of these is the plot of mean size versus standard deviation (fig. 8) which shows that for Mustang Island sorting is practically independent of mean size. The relatively poor sorting of the beach samples is evident on this diagram.

The only plot that shows any correlation

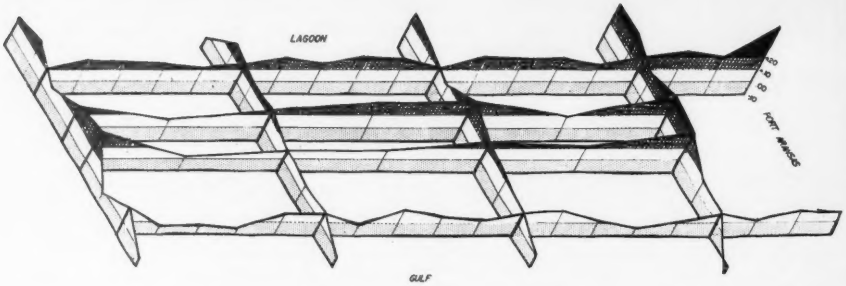

FIG. 7.—Fence diagram, showing variation of skewness over Mustang Island. "Fences" trending to the upper left connect the four crosswise traverses, from Gulf at bottom to lagoon at top; the crosswise distances are greatly exaggerated. The long "fences" represent the lengthwise traverses, in order from the bottom; (1) mid-beach traverse, (2) and (3) dune traverses, and (4) aeolian flat traverse. Note increase in skewness away from the Gulf (readily visible by following each crosswise traverse, skewness values over +.10 shown in heavy shading) and increasing skewness to the northeast (upper right) in the aeolian flat.

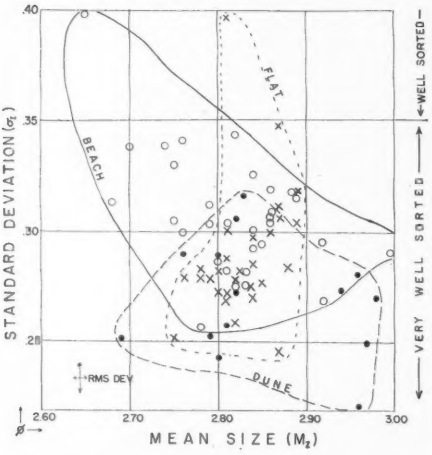

FIG. 8.—Scatterplot of mean size versus graphic standard deviation for all Mustang Island samples. Open circles, beach; filled circles, dune; crosses, aeolian flat. Except for the fact that the beaches are more poorly sorted, there is considerable overlapping of environments; that is this diagram is not very useful in distinguishing these sediments on Mustang Island. Furthermore there is very little overall trend between grain size and sorting except that within the beaches the coarser samples have poorest sorting. Reliability of each data point is indicated by the rms deviation brackets.

between parameters is the plot of skewness versus kurtosis (fig. 9), which shows that high positive skewness is in general associated with leptokurtosis. On this diagram, too, the best differentiation of the samples from the three environments is accomplished: the beach sands yield nearly normal curves, dune sands have nearly normal kurtosis but are positively skewed, while the aeolian flat samples are positively skewed and have high kurtosis.

Why should the plot of skewness versus kurtosis be the most valuable one to use in identifying the environments on Mustang Island? Apparently it is because the source area supplied sand of very uniform mean grain size and superb sorting, and these more basic properties of the sediment are thereby fixed and can only be slightly modified by the dune or beach environments. However, slight differences in mode of transport apparently affect the tails of the distribution considerably, and the character of the tails is precisely what kurtosis and skewness are designed to measure. Only a small amount of sand need be added to or subtracted from the tails to change these parameters greatly, while a large amount of material must be added (or subtracted) to change the mean size or standard deviation substantially. An analogy may be drawn here between sphericity and roundness of pebbles. With a given distance of transport, roundness changes more significantly than sphericity because

roundness measures easily-changed small-scale features (sharpness of corners) while sphericity depends upon the major dimensional ratio which requires much more energy to change, hence is more a function of source.

HYPOTHESIS TO EXPLAIN THE SEDIMENT CHANGES

Heretofore no attempt has been made to explain why the dune sands are better sorted than the beach sands or why the beach sands give normal curves and the aeolian flat samples are positively skewed and leptokurtic. In searching for the geologic reason behind these changes there seems to be no way to prove or disprove the correctness of our hypothesis. The mechanism we propose fits the known facts; whether it is truly the correct mechanism is unknown.

We have seen that skewness and kurtosis

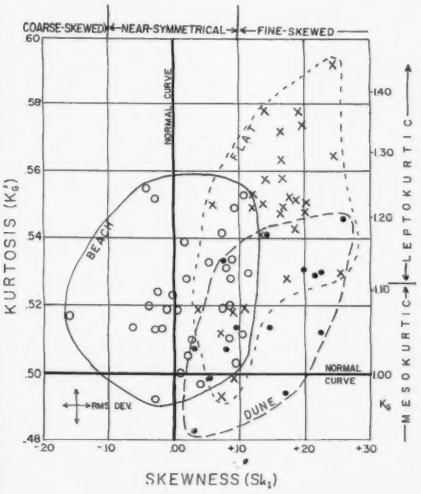

FIG. 9.—Scatterplot of skewness versus kurtosis. Open circles, beach; filled circles, dune; crosses, aeolian flat. This plot is the best means of distinguishing environments on Mustang Island, because the differences between environments are reflected only in the tails of the grain size curves; and skewness and kurtosis are purposely designed to measure the properties of the tails. Beach samples give near-symmetrical, mesokurtic to slightly leptokurtic curves; dune samples are fine-skewed and mesokurtic; and aeolian flat samples are both fine-skewed and leptokurtic.

offer the best means of identifying the environments, that standard deviation also helps, but mean size is worthless. Consequently, differences between samples must be due to additions to, or subtractions from, the "tails" of the grain size curves while the bulk material remains essentially constant. Folk and Ward (1957) proposed that unimodal sediments gave normal curves, and that the cause of skewness and kurtosis was the addition of minor amounts of other normal populations to the sediment—often in amounts not even sufficient to form a secondary mode. Adding 5–10 percent of finer material to a normal population, for example, imparts positive skewness and leptokurtosis. The hypothesis developed below depends on this assumption of modal mixing.

First, one must assume that the direction of sand transport is from the beach to the dunes to the aeolian flat (a direction favored by the prevailing wind). All the sand samples from all environments have as their nucleus a normally-distributed population of grains. This population stays pretty constant in mean (2.80–2.85ϕ) and standard deviation (.28–.30ϕ) although slight fluctuations do occur. This nucleus forms the great bulk of all samples; it is impossible to calculate its exact proportion, but a careful guess would indicate that it forms from 80 to 95 percent of every sample. The differences in environments (which show up as differences in standard deviation, skewness and kurtosis), then are achieved by adding (or subtracting) small amounts of sand to the tails of this nucleus population. At the beach nearest the Gulf, to the nucleus population is added a very small amount of a coarser mode at about 2.0ϕ (?), averaging perhaps 2–5 percent of the sample. These rough figures are obtained by determining where the cumulative curve departs from a straight line on probability paper; beach analyses follow a stright line until they reach about 2.25ϕ (fig. 10) where they begin to curve off slightly. Addition of this slight coarse tail to the parent population (fig. 11) accounts for (1) a somewhat higher standard deviation, (2) slight negative skewness, and (3) slight leptokurtosis. This coarse mode is not shell fragments (which at the most comprise 2 to 5 percent of the fraction coarser

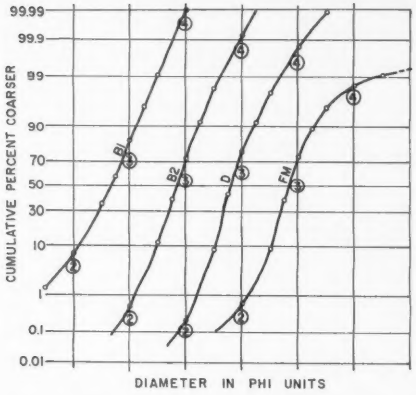

FIG. 10.—Representative cumulative curves from Mustang Island, plotted with probability ordinate. Circled numbers refer to phi diameters of the curves to which they are appended; that is all curves shown have medians between 2.7ϕ and 2.9ϕ. B1 is a typical curve for a beach sample nearest the Gulf; it is the only one that shows negative skewness. B2 is a typical sample from mid-beach, and shows the nearest approach to a normal curve, even when the distribution is carried past the 99.9 percentile. Curve D is a typical dune sample, showing positive skewness (the curve starts to "tail off" to the right after it passes the 90 percentile). Curve FM is a typical aeolian flat sample; note sharp "tailing off" past the 90 percentile, due to addition of a small amount of very fine sand and silt grains. This infiltered fine tail is responsible for the strong positive skewness and leptokurtosis; the central part of the distribution (ϕ25 to ϕ75) is still well sorted, but the tails are now relatively poorly sorted and this imparts a high kurtosis.

than 2ϕ, which itself makes up no more than 2 percent of the sample) but seems actually to be distinct population of coarser quartz grains. This mode is so small in quantity that its very presence is debatable, however.

In the rest of the beach, samples vary from normal curves to those having slight positive skewness (figs 10, 11). Apparently now the coarser mode has dropped out, and these samples represent in essence the unmodified nucleus population because they give curves that are most nearly normal and also have a sorting value coinciding with the average for all samples.

The change from beach to dunes is accompanied not only by improvement in sorting but, strangely enough, also by abrupt development of strong positive skewness. Usually the change in sediments from a normal curve to a positively-skewed one is accompanied by poorer sorting because of the addition of a finer mode to the main population (Folk and Ward, 1957). However, it is possible to obtain a positively-skewed distribution from a normal one by two processes: (1) addition of fine material, the more common process, or (2) subtraction of the coarse end of a normal distribution. On Mustang Island the second process has seemingly operated as the sand travels from the beach to the dunes; elimination or lagging behind of the coarse end of the normally distributed nucleus population results in both improvement in sorting and development of positive skewness, because the curve is now rendered asymetrical with a "pseudo-tail" in the fines (fig. 11).

In the aeolian flat, the curves remain postively skewed and become markedly leptokurtic as the sorting worsens. This can be interpreted as the result of adding a fairly large amount of material (probably windborne infiltration) to the fine end of the distribution (fig. 11). It is estimated that this fine material has a mode at about 4ϕ (silt to very fine sand) and averages about 5–10 percent of the total sample (fig. 10).

One of the notable characteristics of Mustang Island samples is their tendency to be leptokurtic (table 2; fig. 9). Only six of the 76 samples had kurtosis values under 1.00 (K_G′ under .50). This prevalence of kurtosis values slightly over $K_G = 1.00$ seems to be a common feature in samples that are essentially pure sands. One does not have to search far for a reason, however; leptokurtosis is caused by additions of a small amount of a secondary mode (say 3–20 percent) to a primary mode (Folk and Ward, 1957, fig. 19). Addition of this secondary mode serves to worsen sorting in the tails of the distribution while the sorting in the central part of the distribution remains good, hence the curves become leptokurtic. Apparently, then, few sands consist entirely of one mode, and most have small amounts of some secondary mode either coarser or finer than the main mode; this is seemingly the case on Mustang Island.

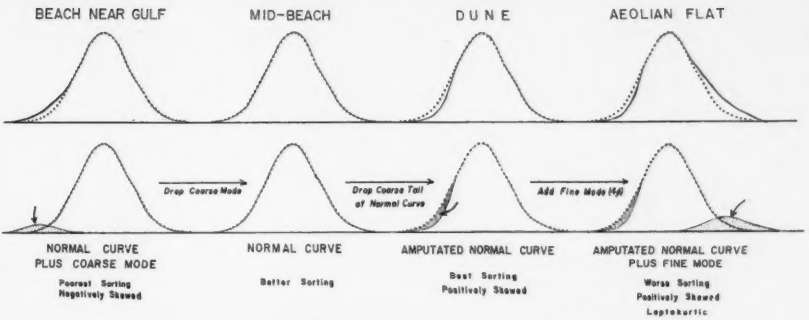

FIG. 11.—Hypothesis to explain the development of different types of grain-size curves on Mustang Island. The direction of transport is assumed to be from the Gulf Beach (left) towards the aeolian flat (right). In each diagrammatic figure, the dotted curve represents a standard Gaussian-normal distribution, of constant shape and placed at constant position to serve as a reference mark. The solid-line curves in the upper row of figures represent the type of frequency curve obtained upon analysis of the actual samples; usually, it departs somewhat from the standard Gaussian-normal curve. The lower set of figures is an attempt to explain *why* the actual sample curve departs from the reference Gaussian curve. It is proposed that a normally-distributed nucleus population forms the great bulk of all samples, and that differences between samples (expressed as departures from normality) are caused by addition or subtraction of grains near the tails of this nucleus population.

The beach near the Gulf is negatively skewed; this is believed to be because of the addition of a very small amount of coarse mode to the nucleus normal population of grains. The mid-beach curve seems to consist very nearly of the pure nucleus normal population of grains; apparently the coarse mode has lagged behind and disappeared, thus the sorting is slightly improved. In passing from the beach to the dunes, the grains in the coarse end of the normal population apparently lag behind; thus the coarse tail is "amputated" (shaded area), causing positive skewness and further improvement in sorting. In the aeolian flat, a fine tail is added by infiltration of 4ϕ material settling out from the atmosphere; this produces marked positive skewness, strong leptokurtosis, and poorer sorting. These causative mechanisms are all hypothetical but appear to fit the observed facts.

TABLE 2.—*Classification of samples as to normality of the distribution*

(Limits after Folk and Ward, 1957)

SKEWNESS

	Coarse-skewed ($Sk_I < -.10$)	Near-symmetrical ($Sk_I -.10$ to $+.10$)	Fine-skewed ($Sk_I > +.10$)
Beach	1	27	3
Dune	0	6	8
Flat	0	6	25
Total	1	39	36

KURTOSIS

	Platykurtic (K_G' under .475)	Mesokurtic (K_G' .475–.525)	Leptokurtic (K_G' over .525)
Beach	0	20	11
Dune	0	8	6
Flat	0	6	25
Total	0	34	42

CONCLUSIONS

Some source (probably the Colorado River) contributes normally-distributed, well-sorted and exceedingly uniform fine sand to Mustang Island, accounting for the remarkable constancy in size and lack of change lengthwise of the island. A coarse quartz mode is retained or added to the normally-distributed sediment only on that part of the main beach nearest the water, possibly because of the higher energy levels existing there. As the sand is blown from the beach and heaped into dunes, the coarse end of the normal size distribution lags selectively behind because the wind cannot carry the coarser grains as easily; thus the dunes become positively skewed and better sorted (fig. 11).

The aeolian flats are very level, grass-covered, and lie at a low elevation. Hence small quantities of coarse silt or very fine sand settle out from the atmosphere and accumulate in the flat, probably filtering down between the coarser grains. The

coarse silt cannot be removed from the flat because of its relative inaccessibility to wind erosion. This infiltered silt tail (fig. 11) imparts positive skewness and leptokurtosis. Source of the silt is not known; it appears to be most abundant at the north end of the island (because skewness is most extreme there (figs. 5, 7), and could conceivably be blown from the mainland during "northers."

This study has shown that grain size analysis is quite successful in distinguishing three environments on Mustang Island and in showing what geologic processes operate to differentiate them. The best way to identify the environments is by plotting skewness against kurtosis, because these properties reflect the changes in the tails of the distribution and the tails are most sensitive to transportive mechanisms. Further studies are being undertaken to see if the same principles apply elsewhere along the Texas coast.

ACKNOWLEDGEMENTS

This paper is the result of a Master's thesis submitted by Mason (1957) to the Geology Department, The University of Texas; the thesis was supervised by Folk. Edward C. Jonas and Raymond C. Staley also served on the thesis committee and offered helpful comments. Dr. Howard Odum assisted in sample collecting and made available the facilities of the University of Texas Marine Station at Port Aransas, and Dr. H. Gordon Damon made many suggestions. Maxine Welch Mason assisted greatly in preparation of the drawings.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 2, PP. 227–229
FIG. 1, JUNE, 1958

NOTES

DESCRIPTION OF A PORTABLE PISTON CORER FOR USE IN SHALLOW WATER[1]

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Department of Biology and the Allan Hancock Foundation, University of Southern California, Los Angeles, California and Shell Oil Company, Ventura, California

In studying the effects of pollution upon aquatic life, it is necessary to know whether the pollutants are accumulating on the bottom and thus affecting the bottom-dwelling organisms. This is particularly important with pollution in bays and harbors. Circulation of the water mass may be poor in the inner reaches of a body of water enabling a greater quantity of pollutants to settle on the bottom. Typically a polluted bottom is composed of black mud which possesses a sulfide odor. The use of a coring device is useful in determining the rate of accumulation of pollutants upon the bottom. This corer was designed to aid in a repopulation and pollution study in an area where there are many fixed or floating docks in water depths of 10 to 30 feet; however, the basic design and operation are simple enough so that it may accommodate many sampling situations.

Many coring devices have been described, most of which are for use in deep oceanic waters (Hough, 1939; Kullenberg, 1947; Anonymous, 1955). Silverman and Whaley (1952) have adapted one of these corers for use in shallow waters. This corer is handled from a boat, fitted with weights, and attached to a cable. Another kind of coring tube, fitted with a valve, was described by Hanna (1954). It is fitted with a stiff handle which limits the working depth, but it has the advantage of not requiring the use of a boat. Ginsburg and Lloyd (1956) described a piston corer which consisted of a plastic tube. Cores up to ten feet in length have been obtained utilizing this instrument in shallow waters. A number of other corers for use in shallow waters have been reviewed by Hough (1939).

The portable coring device described below has many advantages. It is inexpensive and easy to construct. It can be assembled and dismantled with ease and transported in an automobile. It is light in weight and can be operated by one person from a dock, a bridge, or other structures as well as from a boat. It possesses a piston to prevent or minimize compaction. The chief disadvantage, which is characteristic of corers provided with a stiff handle (Hough, 1939), is the flexibility of the pipe which limits the working depth. However, this can be overcome to a certain extent by taking cores from floating docks or boats during low tides. No special maintenance is necessary except for a fresh water rinse and a greasing of the joints after the corer has been used.

DESCRIPTION OF THE CORER

The assembly (fig. 1) includes a brass tube connected to a galvanized pipe. A plastic liner is held in place within the brass tube. A size number 8 cork with a connecting cord, which functions as a piston, is within the plastic liner. It is possible to vary the dimensions of the coring device since all the parts used are standard items.

A 3.0 ft brass tube has an inside diameter of 1.0 in and an outside diameter of 1½ in. This tubing is threaded and connected by a 1 in to ½ in reducing coupling to ½ in galvanized pipe. The cutting edge of the brass tube is tapered for easier penetration. Two holes, measuring ¼ in in diameter, were drilled at opposite sides of the brass tube, a distance of 2¼ ft from the tapered end. Holes were drilled at the corresponding places in

[1] Contribution number 219 from the Allan Hancock Foundation, University of Southern California. This investigation was supported in part by a research grant [RG-4375-(C3)] from the National Institutes of Health, U. S. Public Health Service. Manuscript received November 29, 1957.

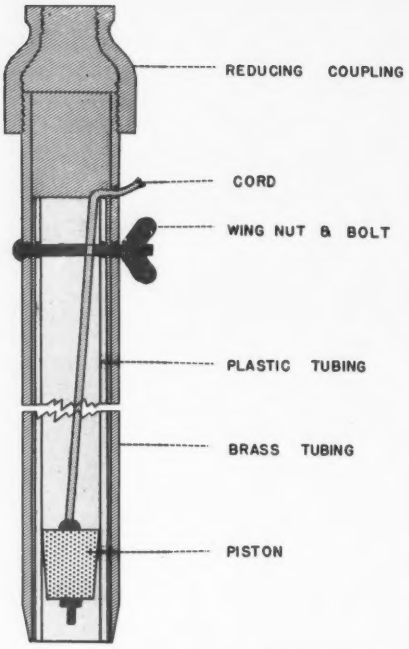

FIG. 1.—Diagram of a portable piston corer.

the plastic liner. A brass wing nut and bolt fastens the plastic liner within the brass tube. A third hole, with the same diameter, was drilled just above the end of the inserted plastic liner. It serves as the exit for the cord connecting to the piston (fig. 1).

The clear plastic liner measures $2\frac{1}{2}$ ft in length and has an outside diameter of 1 in and an inside diameter of $\frac{7}{8}$ in. Two holes were drilled in this tube as described above.

The simplest piston is made from a number 8 cork and a $\frac{1}{8}$ in brass nut and bolt. A more permanent piston of brass with rubber washers is described by Ginsburg and Lloyd (1956). The cord is then attached to the piston (fig. 1).

OPERATION OF THE CORER

The cord attached to the piston is passed from the inside through the single hole in the brass tube. The piston is then pushed with a ramrod into the plastic liner to the end opposite from the one with the drilled holes (fig. 1). The galvanized pipe is then fitted to the reducing coupling with pipe wrenches. Four foot lengths of pipe, which have been marked off in one foot intervals, are used; they are connected with $\frac{1}{2}$ in couplings. Faster coupling could be accomplished by adapting the "quickly detachable joints" of Taylor (1957). The number of pipe sections used varied according to the water depth. As many as seven sections with the brass tube have been used giving a total length of slightly more than 31 ft. The terminal pipe is fitted with a T-joint with $\frac{1}{2}$ ft sections attached on either side. This affords a handle with sufficient leverage during the actual coring.

The corer is lowered slowly into the water until the bottom is reached. The cord attached to the piston is fastened to a rigid structure such as a cleat on the dock in order to hold the piston when the coring tube is pushed downward. One foot intervals had been marked on the pipe, as noted above, in order that the depth of penetration could be measured. The depth is noted at the point where the corer reached the substrate. The corer is then manually pushed into the substrate to a maximum depth of $2\frac{1}{2}$ ft. It is then raised to the surface. It is convenient if the T-joint end of the corer can rest on some structure higher than the dock. A number 4 rubber stopper is placed into the bottom of the plastic tube; frequently it is necessary to remove a portion of the core to make room for the stopper.

To remove the plastic liner, the wing nut and bolt are disengaged. A small screw driver or probe is introduced into the cord hole and the plastic tube is pushed sufficiently so that the opposite end can be grasped. The plastic liner is pulled from the brass tube, the piston and cord still in place. The piston is then pulled slowly from the plastic liner to minimize the amount of disturbance at the surface of the substrate. A number 4 rubber stopper is placed at the open end and the liner is ready for transportation to the laboratory. The core is removed from the plastic liner by pushing with a ramrod fitted with a number 8 cork.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 2, P. 230
FIGS. 1–2, JUNE, 1958

DIP DIRECTION INDICATOR[1]

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The method commonly used to determine the direction of maximum dip of foreset beds with the Brunton Compass Clinometer has been found to be both slow and inaccurate, especially when dealing with easily disturbed, unconsolidated clastic materials. The Dip Direction Indicator, used with the Brunton Compass, simplifies and increases the speed and accuracy of the directional measurement operations.

This indicator is relatively simple to construct and the materials are inexpensive. It is a circular disc, 3 to 6 inches in diameter, of thin aluminum or plastic. A small spirit level is mounted in the center of this disc, and at right angles to the spirit level an arrow indicator is scored or painted on it (fig. 1).

In measuring directional bedding in the field, a three-dimensional aspect of the sediments is obtained by cutting into the cross-bedded sediments and exposing the foreset beds on two sides. The Dip Direction Indicator is inserted along a foreset bedding plane (fig. 2) and rotated until the spirit level is centered. The arrow is pointing in the direction of maximum dip and the azimuth can be obtained with a compass.

This indicator can be readily used in determining the direction of dip and strike of either consolidated or unconsolidated rocks, where it can be inserted in or laid upon the plane to be measured.

[1] Manuscript received March 21, 1958.

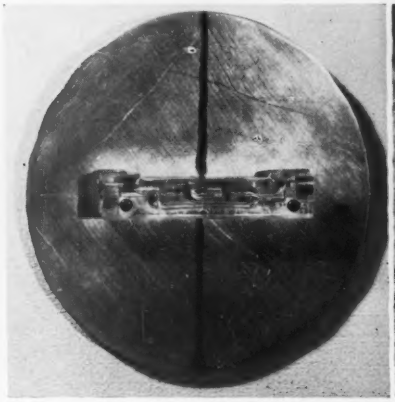

FIG. 1 (left).—The dip direction indicator.
FIG. 2 (right).—Use of the dip direction indicator.

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JUNE, 1958

RAPID REMOVAL OF MARINE SALTS FROM SEDIMENT SAMPLES[1]

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Size (mechanical) analysis of a large suite of marine sediment samples is a tedious process. One of the problems encountered is the removal of marine salts which often cause flocculation if left in the sample. Marine salts are frequently removed by filtering, dialysis, or other methods (Krumbein and Pettijohn, 1938). A search for a rapid, simple, and effective method of removing these salts resulted in the development of a decantation technique detailed below. This technique has the further advantage of requiring no expensive equipment, although it can be much speeded through the use of a large centrifuge. The literature, as yet, contains little or no reference to decantation of marine salts.

Step 1.—A suitable portion of the sediment to be analyzed (about 25 g, dry weight, is suggested) is placed in a 50 ml beaker, dried to constant weight, and the weight recorded. It is covered with distilled water, stirred, and the beaker filled to the brim. The marine salts quickly flocculate clays and fine silts which settle out. The supernatant clear liquid is carefully siphoned off, taking with it a large portion of the dissolved salts.

Step 2.—The sediment is then washed into an eight ounce screw top jar or a 250 ml centrifuge bottle, shaken thoroughly with about 200 ml of distilled water, uncapped, and the sediment washed from the neck and lid of the jar or bottle. It is then left to settle overnight. The remaining marine salts will usually flocculate the sediment in this quantity of water, and in the morning the supernatant liquid is again siphoned off, leaving an insignificant amount of soluble salt in the sediment. Desired size analysis procedures are instituted at this point. Routine dispersion in a tall 1000 ml beaker, which is much more stable and much less expensive than a 1000 ml graduated cylinder, using any of the common peptizers, will result in a suspension which will normally remain free of flocculation for weeks. An occasional sample may have to be split approximately into halves which are analyzed separately and the results combined with allowances for twice the normal amount of dispersing agent.

An alternate procedure for step 2 involves centrifuging the suspension in a 250 ml centrifuge bottle for about ten minutes at 2000 RPM, followed by decantation and the routine analysis procedure desired.

The weight of marine salt removed is usually neglected in the calculation of size parameters, assuming it to be insignificant.

About 1000 marine and brackish water samples have been analyzed using this method. They have been drawn from the Canadian Arctic, the Bay of Campeche, the Mississippi Delta, and from various locations along the Texas coast ranging from offshore banks to bays and estuaries. A few samples from Matagorda Bay, Texas, flocculated after this treatment, and it has been suggested by Dr. U. Grant Whitehouse that these samples may have contained clay minerals of such size and ionic state that flocculation was due not to the marine salts left in the sample but to the clay particles themselves. Some samples from the Bay of Campeche, high in carbonate, flocculated when they were not analyzed immediately after stirring; that is, when stirred, then left for several days in the beakers before remixing with a soil stirring plunger like that figured in Krumbein and Pettijohn (1938).

It seems that the quantity of sample, hence of marine salts, determines the number of decantations, and the volumes of each, required to prevent flocculation. THE ONLY IMPORTANT REQUIREMENT IS THAT ONE CHOOSES VOLUMES OF DISTILLED WATER SUCH THAT FLOCCULATION IN A SMALL VOLUME OF WATER OCCURS OVERNIGHT, WHILE FLOCCULATION IN

[1] *Contribution from the Department of Oceanography and Meteorology, Agricultural and Mechanical College of Texas, Oceanography and Meteorology Series No. 111. Manuscript received February 25, 1958.*

1000 ML OF WATER AND PEPTIZER IS DELAYED FOR THE REQUIRED PERIOD. The second decantation is most often the critical one and the quantity of distilled water suggested herein was arrived at by trial and error.

This technique was developed incidentally to research supported by the Office of Naval Research, Contract #N7onr-48708. The suggestions and assistance of Mr. Dan S. Jackson, which contributed to development of this method, are gratefully acknowledged.

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JUNE, 1958

NEW ABRASIVE FOR SECTIONING WATER-SOLUBLE ROCKS[1]

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"Fabricut," a waterproof cloth mesh impregnated with a granular abrasive manufactured by the Minnesota Mining & Manufacturing Co., St. Paul 6, Minnesota, has been found to produce superior results in the preparation of water-soluble and soft calcarous rocks for thin sections.

This type of abrasive mesh was originally designed for removing varnish, paint, lacquer, and other similar materials which fill ordinary abrasive cloth and paper. While it is slightly more expensive than other types, it has the advantages of abrasive on both sides, produces smoother results, and the grinding debris can be removed by washing the mesh in water. It was also found that fewer scratches were produced by "Fabricut" than other abrasive paper or cloth of comparable abrasive size.

[1] Manuscript received February 1, 1958.

This abrasive mesh is available in both Silicon Carbide and Aluminum Oxide in the following grades: 100, 120, 150, 180, 220, 240, 280, 320, and 400. While aluminum oxide was found to be more desirable for most work, the silicon carbide may be more useful for special problems.

The thin sections are prepared using standard petrographic techniques such as those outlined in the article by Reed and Mergner (1953) except that the rock slice is ground by hand on the dry "Fabricut" without the use of a lubricant.

Due to the greater amount of heat produced by the dry abrasive, care must be taken not to soften the bond between the rock slice and the glass slide. It is best to use several grades of "Fabricut" during the grinding process to eliminate scratches and reduce the grinding time.

REFERENCE

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JUNE, 1958

DISCUSSION

A DEFENSE OF THE TERM ALTERITE

TJEERD H. VAN ANDEL[1]
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Recently Dorothy Carroll (1957) has discussed and condemned the use of the term "alterite" in heavy mineral studies. The present author coined this term in 1950 for the special needs of a study of the heavy minerals of the Rhine. The alterites in the Rhine are fine-grained, frequently rounded translucent grains of unknown composition. They are very characteristic for sediments of alpine derivation. Later work with sediments of various ages from different parts of the world has shown that alterites are common and often diagnostically important. A few words in defense of the term may therefore be said.

The author is in complete agreement with Miss Carroll where she criticizes the indiscriminate use of the term without proper definition. As a group term "alterite" is necessarily vague and it is virtually meaningless without a description of the grains included. It is also true, as Miss Carroll states, that such group terms might become a convenient "sack" for anything not easily identified and that its use might encourage lazy mineralogists. The present author, however, prefers to believe that most students of heavy minerals seriously strive to identify each grain before resorting to the extreme measure of group classification. It appears to be Miss Carroll's experience that in such an attempt few if any grains would remain unidentified.

It is on this point that we must disagree. In the Rhine study several types of alterites have been distinguished according to parent minerals (epidote-alterite, hornblende-alterite, etc.). This does not imply that it is possible to apply this subdivision to all alterites. On the contrary, most of the grains definitely defy every attempt to identify the parent mineral. Since the coining of the term the author has seen many thousands of alterites. For the very large majority of these an identification of the parent mineral was absolutely impossible. It may be stated here in passing that the alterite group never was meant to be a collective name for all unidentifiables, unknowns or dirty minerals, but is definitely restricted to one specific group.

Although mineralogically of unsatisfactory character, the alterite group is often of diagnostic value (see, for example, de Jong 1956, Groot 1955, van Andel 1955). In this respect we may compare the alterites to the opaque group. Opaque percentages are often important; still, the number of cases where separate opaque minerals have been, or easily could have been, identified is small.

If the use of the term alterite would not be permitted, what should we do? Should the individual alterites be forced into mineralogical species although most often one cannot be sure about the correct identification? The present author would much rather encounter the term alterite with all its implied vagueness and be sure that species identification has been difficult than to have to doubt all hornblende, epidote, or pyroxene percentages. Or should we simply omit all deeply altered grains from our counts? That would deprive us of a group of diagnostically valuable elements. After all, most of us are studying heavy minerals not for their mineralogy, but in order to investigate sediment sources, stratigraphy, and related problems.

Therefore, it is the author's considered opinion that the use of group terms like alalterite is not only justifiable but in many cases desirable if applied with caution and if properly defined for each case.

[1] Contribution from Scripps Institution of Oceanography.

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JUNE, 1958

REVIEWS

Petrographic Modal Analysis, by Felix Chayes, 1956. Pp. x×113, 15 figs., 15 tables; $5\frac{3}{4}\times9$ in., cloth. John Wiley & Sons, Inc., New York, and Chapman and Hall, Ltd., London. Price $5.50.

Chapter 1 discusses the geometrical basis of modal analysis with the introductory statement that the theoretical validity of modal analysis is independent of petrography and is dependent on probability considerations only. A logical sequence is then presented going from point sums as estimators of relative areas using a "Venn diagram" illustration to parallel lines as estimators of relative areas and finally to the Delesse relation. This last is a statement that the ratio of area occupied by a given mineral to the area occupied by all the other minerals is a consistent estimate of the volume percent of the given mineral in the rock. In this way Chayes sets the foundation for the selection of traverses over a thin section, the use of traverses to estimate areas, and the immediate extension of areas in the thin section to volumetric conclusions.

An interesting statement on p. 12 is given in quoting from current statistical work that systematic sampling does not introduce serious bias (except where linear or periodic trends are present). The problem of sampling in geologic studies in general, as well as in modal analysis, appears to rest at least in part on the mathematical convenience of random sampling *vs.* systematic sampling so arranged as to insure inclusion of all the phenomena of interest.

In my opinion the first chapter is the key to the book, and should be read and digested with care in order to follow and understand the remainder.

Chapter 2 discusses the modal analysis of banded rocks. We may here refer back to the statement above that bias in systematic as opposed to random sampling is not serious except where linear or periodic trends are present. In the present chapter attention is focused on lineation, foliation, and banding. These come under the category of linear or periodic trends. Chayes offers no general solution to the problem of how to arrange the traverses in rocks which exhibit the above mentioned orientation features.

He does however focus attention on what appears to be the heart of the matter, namely that degree of random analytical error is dependent on which sampling plan is used, but that the fundamental Delesse relation of inference from area to volume is independent of presence or absence of orientation features. The problem then becomes one of sampling technique dependent on the nature and degree of orientation in the rock. Cloudy considerations of when a rock is "sufficiently oriented" to preclude modal analysis are thus dismissed.

Chapter 3 discusses methods of measuring relative areas in thin sections, and chapters 4 and 5 discuss in some detail the degree of reproducibility in thin-section analysis.

Chapter 7 through the rest of the book is concerned primarily with the reliability of inference from thin section to hand specimen. The final step (irrelevant to the purpose of this book, however) should then be the similar reliability of inference from hand specimen to outcrop or outcrop to formation.

Of particular interest to the sedimentologist is the discussion of Chapter 8, the effect of grain size and area of measurement on analytical error. The sedimentologist is (as the literature shows) far more preoccupied with grain size than is the "hard rock" geologist. However, this seems justified in terms of the detrital nature of many of the rocks he has to deal with. For example, grain size is important as one means toward identifying or inferring dynamics of transport and deposition. In such a case the transition from size distribution in contempory unconsolidated sediments to that of consolidated rocks is important. Clearly it is useful to know how well size analysis in thin section (for example, by linear traverse techniques) compares to size analysis in unconsolidated material by sieve or settling techniques.

Chapter 9 discusses coarseness in granitic fabric. The IC number is introduced. It is defined as the number of major mineral identity changes along a unit length of line. This practical measurement is used to differentiate between several granites. The relation between analytical error and "identity change" (IC) numbers is discussed, and

this is then carried over to control of analytical error by replication (chapter 10). The final chapter (11) discusses the lower limit of coarseness. The finer grained the rock, the greater the analytical error in modal analysis. Thus there exists a lower limit in the size, below which modal analysis may no longer be reliably used.

The book closes with two appendices, the first giving selected statistical references, the second an expansion of section in chapter 2.

I feel that this is an outstanding book from several aspects. For the geologist interested in modal analysis it should be an indispensable reference. For the geologist interested in the application of clear cut reasoning, involving the application of statistics and probability theory wherever it seems useful, the book is highly recommended. It is well worth the extra time and care that is necessary to read it properly.

ROBERT L. MILLER
University of Chicago

Principles of Stratigraphy, by Carl O. Dunbar and John Rodgers, 1957. Pp. xii+356, 123 figs., 21 tables; $7\frac{1}{4}\times10$ in., cloth. John Wiley & Sons, Inc., New York. Price $10.00.

Stratigraphy, one of the basic areas of geology, has been taught throughout most of the history of the science without the aid of a textbook. By tradition it has been taught from lecture notes carried forward from one generation to another. The methods of approach have been almost as numerous as the people who taught it, and the effectiveness of teaching has depended upon the personal experience of the individual. Naturally, the results have not always been satisfactory.

In "Principles" we have at last a most satisfactory solution to the textbook problem on the graduate level. Dunbar and Rodgers have written a text of high caliber; a book that is certain to fulfill a need. "Principles" gives a thorough discussion of the basic concepts in the field of stratigraphy. These concepts are discussed on a level directed toward the graduate student and the professional geologist. For such mature students of geology, "Principles" is a must.

The text is composed of four parts—Environment of Deposition, Basic Stratigraphic Relations, Interpretation of Specific Lithotopes, and Synthesis. After an analysis of sedimentary processes, non-marine, marine, and mixed environments are discussed. Original sources and examples are cited for almost all important points discussed. Photographs and illustrations are exceptionally well-chosen. The illustrations and examples are among the very attractive features of the entire book.

The section on environment is followed by a discussion of the stratigraphic relations of sediments. This excellent section portrays the importance of unconformities and facies in modern concepts of stratigraphy. In general, there is a splendid choice of subject matter. The discussion of facies and rock correlation leaves little to be desired. There is an impartial treatment of controversial viewpoints and a good historical development of the problems. The thorough discussion given of most of the basic problems in stratigraphy should be of distinct advantage in the training of future geologists. At least, they have available to them an expression of modern concepts and will not be forced to rely upon outmoded ideas.

HAROLD W. SCOTT
University of Illinois

Elementary Crystallography, by M. J. Buerger, 1956. Pp. xxiii+528, 618 figs.; 69 tables: $6\times8\frac{1}{2}$ in., cloth. John Wiley & Sons, Inc., New York. Price $8.75.

Geologists (so goes a current cliche) deal primarily with naturally occurring substances in the solid state—that is to say, with minerals. This being so, *every* geologist should at least be acquainted with the principal directions of approach leading to an understanding of these crystalline materials.

One such approach, the atomistic one, attempts to explain the nature and behavior of minerals in terms of their chemical constituents. The other more abstract crystallographic approach and the one treated in the book under review provides a check, independently of atomistic conceptions, on the permissible arrays of objects in space. Any atomic structure proposed by chemical reasoning must conform to the conditions specified by crystallographic reasoning. The crystallographic approach also affords the necessary means for describing and relating the

vectorial properties so characteristic of crystalline substances.

These matters are of interest not only to the specialist in mineralogy, but are of the utmost importance to anyone who wishes to wrest the greatest possible amount of geological information and technological use from minerals, be they in sedimentary rocks, soils, plutonic rocks, or mineral deposits.

This is the first book in English which exposes in a thoroughly rational, step-by-step, comprehensive, and modern way the mystic rites of crystallography. Indeed, a great many conventionally trained geologists probably will discover that the subject is quite different from what they had supposed, and certainly far more logical and interesting.

The principal aim of the book is to demonstrate the kinds of space patterns possible in crystals and the mental methodology necessary for their analysis. The approach is based upon the conception of crystallography as a special kind of solid analytical geometry—that of *repetitive* space.

The first half of the book develops a detailed explanation of megascopically observable symmetry. The chief topics considered are: nature of repetition theory, types of repetitive operations, permissible combination of them (the 32 classes), lattices, coordinate systems, crystal forms, and point group determination.

Most of the second half of the book is devoted to a detailed analysis of the possible internal symmetries, leading ultimately to the development of each of the 230 space groups. A chapter on space group determination and its use essentially completes the development.

A final three chapters introduces the reader to the application of the *theory of groups* to space group development in contrast to the analytical approach in the rest of the book.

The text explanations are fully illustrated by a great many diagrams and tables. Chapter 16 alone has 194 figures! Readers should be properly appreciative of the enormous labor by the author and publisher in making these helpful aids available.

Non-specialists need not wade through all the details to obtain a good insight into the nature and powers of crystallography. A selective reading will serve this purpose. A preliminary reading of the first two pages of chapter 17 at an early stage probably will provide a helpful perspective.

Elementary Crystallography is a valuable addition to the geological book shelf and should have a considerable effect in bringing about long needed changes in crystallographic and mineralogic education in the United States.

Although the development in the book is not difficult, no doubt some readers will feel the author has scored a neat ploy in "geomanship" (cf. Potter, 1955) with the title. However, if anyone considers this treatment too difficult for the undergraduate level, he should have a look at the problems given by Terpstra (1953) to undergraduates and others in the Netherlands!

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D. M. Henderson
University of Illinois

Geologic Field Methods, by Julian W. Low, 1957. Pp. xv and 489, 214 figs., 11 tables, 4.8×7.3 in., cloth. Harper & Brothers, New York. Price $4.50 (Text edition); $6 (Professional edition).

Julian W. Low's *Geologic Field Methods* is a great deal more than the title advertises it to be. It is a handy-dandy, do-it-yourself, pocket-sized manual on how to plan for, live in, work in, and return from the field; as such, it accomplishes the objectives of its author in a most striking fashion.

Low's peculiar writing talent is his outstanding ability to write clearly, concisely, and yet completely about the methods of geology. Perhaps the most useful feature of this book is his concern with the techniques of doing even the most elementary of tasks efficiently. He leaves little to the "common sense" of the reader who, if he is a novice in the field, lacks the experience upon which "common sense" is based.

In the first three chapters, Low defines and considers the principles underlying good field work, outlines the steps necessary to the organizing of a field project, and discusses the rudiments of camping and sur-

viving in the field; chapter III closes with a paragraph (p. 60) on the responsibility of the geologist to the profession, to his employer, and to the owners of property to which he wishes access. These may be the most important chapters written about field geology in years. Who can deny the truth of Low's expressed opinion that the success of an expedition often rests as much or more upon proper planning, skillful living, and good public relations as it does upon selection and skill in the use of the most appropriate field methods?

Succeeding chapters take up specific field techniques (IV through VIII), related subsurface methods (IX), and the planning and use of illustrations (X). Careful, step-by-step explanations which reduce each procedure to its simplest terms characterize this portion of the book also. The teacher (whether he goes by the title of professor, or district, division, or chief geologist) who has seen his students, faced with field work for the first time, mill about while they wonder what proportion of the subject matter discussed in the classroom actually applies in the field will welcome this straight-forward approach. The student who wishes to look wise in the ways of a field geologist as he describes his first outcrop, takes his first strike and dip, or measures his first section will also be happy to find it. The party-chief charged with organizing and directing a field project will find the book useful in the planning stages as well as after he arrives in the field.

Each of us could quarrel with Mr. Low about aspects of field work which have been omitted from his book. However, in order to accomplish his objective of writing a manual of a size convenient to carry in notebook carrier or pocket, it was necessary for him to be selective; *Geologic Field Methods* is remarkably broad in its treatment of the subject. Written as it is in a clear unpretentious style, abundantly illustrated with sketches, line drawings, maps, cross-sections, photographs, and tables, the book is an important contribution to the literature of geology.

WILLIAM M. MERRILL
University of Illinois

Introduction to Microfossils by Daniel J. Jones, 1956. Pp. xviii+406, 94 figs., 6×9 in., cloth. Harper and Brothers, New York. Price $6.50.

The number of students who study microfossils has grown to such an extent that they appear to out-number those who study the large invertebrates. Even though micropaleontology has had a remarkable development in the past 38 years, a general American text in the subject has never been available. Jones' "Introduction to Microfossils" is the first to fill this void.

After introductory chapters on history, techniques, and general classification Jones gives a more detailed classification of various groups, including the Protista, plant microfossils, microfragments of megascopic fossils, conodonts, ostracods, and foraminifera. For each group he gives a brief discussion of morphology, basis of classification, and family characters. Most of the important genera are illustrated by line drawings. Some of the illustrations lack detail, such as hinge structure in the ostracods, but as a whole they clearly portray the essential features.

Concluding chapters on Environment and Applied micropaleontology present short discussions on these subjects and might well be enlarged in subsequent editions. The chapter dealing with applied micropaleontology could be incorporated into the treatment of "Stratigraphy." The sentence outline method used in the chapter on "Stratigraphy" might be more useful if each group had been carried through its geological range separately.

The glossary of generic and specific names, the general glossary, and the numerous references will be very useful.

Jones did not intend this book to be a reference work or treatise on any special group. It was prepared as an introductory level text-book and the beginning student in micropaleontology should find it useful in his attempts to become acquainted with the major and minor groups of microfossils.

HAROLD W. SCOTT
University of Illinois

Die Quarzkornfarbe als Hilfsmittel für die stratigraphische und Paläogeographische Erforschung sandiger Sedimente.

and

Die Lithologie und Paläogeographie des Buntsandsteins am Westrand der Böhmischen Masse. By Walter A. Schnitzer. 1957, Erlanger Geologische Abhandlungen, Heft 23 and 24.

In these two interesting contributions the author presents a new tool for the stratigraphic and paleogeographic investigation of arenaceous sediments by using the natural colors of quartz grains belonging to the size fraction 2–1 mm. In this fraction, the quartz can be easily separated from the feldspars. It is then thoroughly cleaned in boiling HCl for 30 minutes in order to get rid of the iron, manganese, and clay mineral combinations whose coloring effects would interfere with the natural color of the quartz.

Investigations in the Buntsandstein and Keuper of eastern Bavaria performed by the author have disclosed that the color of the quartz grains can be used for stratigraphic subdivisions and that the results are in agreement with those obtained by the conventional study of the heavy minerals suite. In many cases, it even appears that the study of the color of the quartz grains gives better results than the heavy minerals investigations, particularly in the identification of alluvial fans and their interference patterns in the Buntsandstein.

The advantage of the proposed method is its simplicity and usefulness even in the field. Further studies, however, are required to check how the method will work in the cases of long distance transportation and to what extent the original color of the quartz grains is modified by facies and diagenetic processes, particularly when the quartz is associated with highly kaolinized deposits or with radioactive minerals. However, the method is still useful since other investigation tools such as granulometry and heavy mineral analyses are also similarly affected by facies and diagenesis.

ALBERT V. CAROZZI
University of Illinois

Chemistry in Introductory Geology, by W. D. Keller, 1957. 84 p, 15 figs.; $5\frac{1}{2}\times9\frac{1}{2}$ in., paper. Lucas Bros. Publishers, Columbia, Mo.

The teachers of introductory geology have always been faced with a difficult problem. Many of the processes they discuss require a knowledge of elementary (and sometimes not so elementary!) chemistry, but only a small percentage of the students have had even high school chemistry. The alternatives are to delete material requiring chemistry from beginning geology or to attempt to teach, in few but well chosen words, the knowledge required.

Professor Keller has made a valiant attempt to put the necessary chemistry into a short ring-bound booklet. As he says, "The purpose of this booklet is to provide in language easy to read, a simplified but sound approach to the concepts of chemistry most commonly used in introductory geology, and to illustrate with practical geologic examples."

In the reviewer's opinion, the booklet is useful only in part for the student who has had some chemical training, but could be most helpful to one who has had a year of high school or college chemistry. The difficulties stem from the mistake that is always made by an author who has used chemistry for a number of years—he forgets where the line is drawn between his knowledge specifically drawn from his chemical training, and that general body of information which can reasonably be expected to be at the command of an eighteen-year-old college student

To test this conclusion, I asked severa intelligent but chemically uninformed college graduates to read the book and to give me their comments. They found the text very difficult, largely because of undefined terms—for example, Brownian movement, isotope—or because of too-brief explanations. The metric system is described in a footnote, and the use of power notation (1.5×10^{-24}) in another. As a further example of the same kind of thing, a drawing of the structure of montmorillonite on page 51 is labelled in terms of b-axis and c-axis, which are terms not explained, and the formula $CaSO_4 \cdot H_2O$ is presented without explanation of the dot.

So far as the material covered is concerned, the booklet is a convenient summary of a great deal of useful information. Major chapter headings are: "The materials of the earth in terms of elements, atoms, ions, and compounds," "The magma and

its products," "Chemical weathering," "Deposition of chemical sediments," "Colloids in geology," "Chemical reactions in metamorphism," and "Deposition of ore minerals."

There are a few typographical errors that will easily be remedied in a second printing, and there are a few technical aspects that could be improved by rewriting present material or by revising to include more recent data. There is a certain amount of confusion resulting from simultaneous use of a molecular [$Ca(HCO_3)_2$], as well as an ionic [$Ca^{++}+2HCO_3$] terminology. Current usage would soft-pedal the importance of undissociated calcium bicarbonate molecules in aqueous solutions.

In summary, the booklet is useful as it stands, but chiefly to students with a year or more of chemistry. To be satisfactory for the non-chemist, it should be expanded; to be entirely acceptable to the user with chemical training, some parts should be rewritten slightly upwards. The subject matter is well chosen; if released from the impossible (?) burden of condensing a large amount of chemistry into an elixir digestible by a complete novice, the author could produce a volume indispensable for undergraduate majors in geology who have had a year or more of chemistry.

R. M. GARRELS
Harvard University

ANNOUNCEMENTS

SEVENTH NATIONAL CONFERENCE ON CLAYS

The Seventh National Clay Conference will be held on October 20 to 23, 1958, in Washington, D. C. at the U. S. National Museum in the Natural History Building of the Smithsonian Institution and will be open to all who have a common interest in clays and clay technology. It is sponsored by the Clay Minerals Committee of the National Research Council and is under the Chairmanship of Dr. H. F. McMurdie of the National Bureau of Standards.

A principal theme for the conference will be "Geology of Clay Deposits." However, papers will also be presented on other phases of the broad subject of "Clays and Clay Minerals." A field excursion is planned for Monday, October 20, to typical clay deposits and soil profiles in northeastern Maryland and northern Delaware. A guided tour to the National Bureau of Standards is being arranged for the afternoon of the 22nd. Complete details of the program will be announced in August.

PUBLICATION OF A FRENCH TRANSLATION, "LES METHODES D'ETUDE DES ROCHES SEDIMENTAIRES," OF A RUSSIAN SYMPOSIUM ON THE METHODS OF STUDY OF SEDIMENTARY ROCKS

The Bureau de Recherches Géologiques et Minières, with the cooperation of French sedimentologists, is preparing a French translation of the important Russian symposium on the methods of study of sedimentary rocks, edited by N. M. Strakhov (principal editor), G. I. Buchinskii, L. V. Pustovalov, A. V. Khabakov, and I. V. Khvorova, Moscow, 1957.

The content of the book is as follows; Tome I, 611 pages, 74 plates, 133 figures, 58 tables; Tome II, 564 pages, 15 plates, 154 figures, 55 tables. Printing is by offset. The pre-publication price of the book is 10,000 Frs.; after publication the price will be higher. The subscription is to be paid to; B.R.G.G.M. (S.I.G.), 74 Rue de la Fédération, Paris XVe, France. Postal current account; Paris—9060—41.

The translation is being published at cost. Announcement submitted by A. Vatan.

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SOCIETY RECORDS AND ACTIVITIES

REPORTS AND MINUTES OF THE THIRTY-SECOND ANNUAL MEETING OF THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

The thirty-second annual meeting of the Society of Economic Paleontologists and Mineralogists was held in the Renaissance Room of the Biltmore Hotel, Los Angeles, California, March 10–13, 1958, in conjunction with the annual meeting of The American Association of Petroleum Geologists.

The program consisted of a joint meeting with the A.A.P.G. with papers on Problems of Correlating and Interpreting Sedimentary Facies being presented. The Society's program consisted of papers on Silica in Sediments, Paleontology and Stratigraphy, and Sedimentary Mineralogy and Petrology.

Due to illness in the family of President R. V. Hollingsworth, he was not present to give the S.E.P.M. presidential address at the joint session on Tuesday, March 11.

At the joint session on Tuesday morning, Honorary Membership Scrolls were presented to Charles E. Decker, Marcus A. Hanna, and Hans E. Thalmann.

Charles E. Decker, a charter member of the S.E.P.M., was born in Dixon, Illinois, on September 27, 1868. Thirty-eight years later, in 1906, he received his B.A. degree from Northwestern University and in 1917 his Ph.D. in geology from the University of Chicago. Dr. Decker became an instructor in geology at Oklahoma University in 1916, advancing to assistant professor, associate professor, professor, and in 1930 to head of the Department of Paleontology. In 1943 he became professor emeritus in the School of Geology.

At the age of 85, in 1953, he launched a 5-year research program, an alumnus of the University making his project possible by establishing the Decker Research Fellowship through the O. U. Foundation. Naturally, the study concerns graptolities, as Dr. Decker is an acknowledged world authority on the tiny marine fossils which are often keys in determining the age of formations.

Dr. Decker was elected secretary-treasurer of The American Association of Petroleum Geologists 7 times. In 1927 he became one of the A.A.P.G.'s first honorary members. For 6 years he was secretary-treasurer of Sigma Gamma Epsilon, national geology fraternity and from 1924 to 1932 he served as president.

Dr. Decker was president of the S.E.P.M. in 1931 and in 1934 was president of the Oklahoma Academy of Science. He is a fellow in the Geological Society of America and the American Association for the Advancement of Science. He is an author of many papers and his research articles have been published in the A.A.P.G. *Bulletin*, the *Journal of Paleontology*, and the Oklahoma Academy of Science.

Marcus A. Hanna, chief paleontologist for the Gulf Oil Corporation, Houston, Texas, and a charter member of the S.E.P.M., was born in Neosho County, Kansas, on February 24, 1898.

In 1920 he received a B.A. degree in geology from the University of Kansas. He

CHARLES E. DECKER
Honorary Membership

was a teaching fellow at the University of California from 1920 until 1922, during which time he completed his resident work toward a Ph.D. degree in geology, the degree being conferred in 1926. His Doctor's Thesis was entitled, "Geology and Paleontology of La Jolla Quadrangle, California."

Before joining the Exploration Department of the Gulf Oil Corporation in Houston, Texas, in 1924, Hanna was an instructor in geology and paleontology at the University of Washington in Seattle (1922–1924).

His scientific affiliations, in addition to S.E.P.M. active membership, include the Geological Society of America (fellow), The American Association of Petroleum Geologists (active member), Paleontological Society (fellow), the American Petroleum Institute, The American Association for the Advancement of Science, and the Houston Geological Society.

Dr. Hanna was secretary-treasurer of the S.E.P.M. from 1927 to 1929 and president from 1929–1930, in addition to being an associate editor for a number of years. He was vice-president of the Paleontological Society in 1934 and served as secretary and president of the Houston Geological Society in 1928 and 1934 respectively.

Hanna's publications include some 35 papers in technical and scientific Journals, including the *Bulletin* of The American Association of Petroleum Geologists, the *Journal of Sedimentary Petrology*, and the *Oil Weekly*. He has also published several papers on Foraminifera in our *Journal of Paleontology*.

Hans E. Thalmann, a charter member of the S.E.P.M., was born in Berne, Switzerland, on January 3, 1899. He received his Ph.D. degree from the University of Berne in 1922. Dr. Thalmann's experience includes many years of research and company affiliations abroad. For 7 years he was associated with the Shell Oil Company in Mexico and the Netherlands. In Sumatra he was paleontologist for a number of years for Bataafsche Petroleum Maatschappij and then for 6 years was chief paleontologist for Standard-Vacuum Oil Company there, until the Japanese invasion at which time he was trans-

Roulande Studio, Houston

MARCUS A. HANNA
Honorary Membership

HANS E. THALMANN
Honorary Membership

CHRISTINA LOCHMAN-BALK
BEST PAPER AWARD, 1956
Journal of Paleontology

Goertz, Edmonton

MAURICE A. CARRIGY
BEST PAPER AWARD, 1956
Journal of Sedimentary Petrology

ferred to Ecuador. Dr. Thalmann has been a professor at Stanford University for many years.

In addition to his membership in the S.E.P.M., Thalmann is a member of The American Association of Petroleum Geologists, the Geological Society of America, and numerous foreign Societies. He was president of the S.E.P.M. in 1954.

The Society and paleontologists in general who read the *Journal of Paleontology* are greatly indebted to Dr. Thalmann for the fine contribution he is making with his annual Bibliography of Foraminifera. This has appeared yearly since 1933 and his painstaking efforts are certainly appreciated by the geological profession. Another important contribution by Dr. Thalmann is the 25-year Index of the *Journal of Paleontology* which is now ready for publication.

In addition to the above awards, at the Tuesday afternoon Business Session of the S.E.P.M., Research Committee Chairman H. A. Ireland presented the Society's Award for the Best Paper for 1956 in the *Journal of Paleontology* to Christina Lochman-Balk, for her paper entitled, "The Evolution of Some Upper Cambrian and Lower Ordovician Trilobite Families," which appeared in the May issue, Volume 30, Number 3. Mr. Ireland also presented the award for the Best Paper for 1956 in the *Journal of Sedimentary Petrology* to Maurice A. Carrigy, for his paper entitled, "Organic Sedimentation in Warnbro Sound, Western Australia," which appeared in the September issue, Volume 26, Number 3.

The Best Paper Awards are the fourth to be presented by the S.E.P.M. They consist of a certificate given to the author whose paper, appearing in the Journals during the second preceding year, is judged by the Research Committee to be the most outstanding contribution of the year.

Born in Springfield, Illinois, on October 8, 1907, Mrs. Balk graduated from the Springfield High School in 1925 and in 1929 received a B.A. degree from Smith College (summa cum laude). After obtaining a M.A. degree from the same institution, she did

graduate work at Johns Hopkins University, receiving her Ph.D. degree in 1933. In 1934, Mrs. Balk was the recipient of a National Research Council Grant for study of the Cambrian of Llano District, Texas.

From 1935 until 1947 Dr. Balk taught geology at Mount Holyoke College, advancing from instructor to associate professor. She has lectured in geology both at the University of Chicago and Johns Hopkins University. From 1955 until 1957, Mrs. Balk was stratigraphic geologist with the New Mexico Bureau of Mines and since 1957 has been a professor of geology at New Mexico Institute of Mining and Technology, Socorro, New Mexico.

In addition to her membership in the S.E.P.M., Dr. Balk is a member of Sigma Xi, American Association for the Advancement of Science, Paleontological Society, Geological Society of America, and New Mexico Geological Society.

Maurice A. Carrigy, was born in Sydney, Australia, on December 5, 1928. He entered the University of Western Australia in 1947 and graduated with a B.S. degree in 1949 and B.Sc. honours in 1950. In January, 1951, he was awarded a Commonwealth Research Grant to study recent sediments and processes of sedimentation on the Western Australian continental shelves. As a result of this work he published two papers. One in 1954, in collaboration with R. W. Fairbridge, entitled, "Recent Sedimentation, Physiography and Structure of the Continental Shelves of Western Australia," appeared in Volume 38 of the *Journal* of the Royal Society of Western Australia, and the other, entitled, "Organic Sedimentation in Warnbro Sound, Western Australia," is the subject of this award and was included in a thesis submitted to the University of Western Australia for the M.S. degree which was conferred in February, 1957.

In June, 1952, Mr. Carrigy relinquished his Commonwealth Research Grant to take up a position as Research Officer in the Soil Mechanics Laboratory of the Main Roads Department of Western Australia, and in June, 1957, he joined the staff of the Research Council of Alberta, Edmonton, Alberta, Canada, to work on the Lower Cretaceous Sediments of the Athabasca Oil Sands.

Mr. Carrigy's affiliations include membership in the Geological Society of Australia, the Royal Society of Western Australia, and the Australian and New Zealand Associations for the Advancement of Science.

ANNUAL BUSINESS MEETING

The annual business session of the Society was called to order at 1:30 P.M., Tuesday, March 11, by Stuart A. Levinson, vice-president, who introduced the officers for the new year as follows: President, Gordon Rittenhouse; Vice-President, William M. Furnish; Secretary-Treasurer, Raymond E. Peck; Editors of the *Journal of Paleontology*, M. L. Thompson and C. W. Collinson; and Editor of the *Journal of Sedimentary Petrology*, Jack L. Hough. Mr. R. V. Hollingsworth remains a member of the council as Past-President.

It was moved, seconded, and carried that the minutes of the 1957 meeting be approved as published in the June, 1957, *Journal of Sedimentary Petrology* and the July, 1957, *Journal of Paleontology*.

Acting President Levinson gave a resume of the following reports; these, however, are being printed in full:

1. *Report of the Editor of the Journal of Paleontology* (*M. L. Thompson*).—Volume 31 of the *Journal of Paleontology*, issued in conjunction with the Paleontological Society, contains 1,190 pages and 150 plates of fossil illustrations. There are 71 titles plus paleontological notes, reviews, subject-author index, society records and activities, notices, and announcements. This volume represents a decrease of 204 pages and an increase of 4 plates over the preceding year but is within only a few pages of a 10 year average preceding Volume 30. That part of Volume 31 sponsored by the S.E.P.M. (Numbers 2, 4, and 6) contains a total of 506 pages and 78 plates, and contains 24 papers, 10 paleontological notes and discussions, and several reviews. About 30 percent of the contributions are from outside North America.

The S.E.P.M. part of Volume 31 contains papers that deal with a large variety of fossil groups, as well as timely discussions of modern shell-bearing invertebrates. Unlike the S.E.P.M. part of many earlier volumes, a majority of the papers are concerned with faunas of Paleozoic age. The stratigraphic breakdown shows 18 papers on Paleozoic fossils, three on Mesozoic fossils, and five on

OFFICERS OF THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS, 1958–1959

Seated, left to right, R. E. Peck, Secretary-Treasurer; Gordon Ritten house, President; W. M Furnish, Vice-President; standing, left to right; J. L. Hough, Editor, *Journal of Sedimentary Petrology;* M. L. Thompson and C. W. Collinson, Co-Editors, *Journal of Paleontology.*

Cenozoic fossils. A majority of the papers in the volume are on fossils generally termed megafossils but the S.E.P.M. numbers have 13 papers on microfossils and 12 papers on macrofossils. About 64 percent of the S.E.P.M. text is devoted to microfossils. Most are published within less than a year after final receipt of the manuscripts. The supply of unpublished manuscripts has remained equivalent to about a complete number of the *Journal* in advance of publication.

The March issue of this volume was handled by the former S.E.P.M. editor, Dr. W. M. Furnish. Special thanks are extended to him for making a trip to the present editor's offices at Lawrence, Kansas, and spending considerable time going over all phases of editorial problems before his responsibilities ended. The University of Kansas and the Illinois State Geological Survey contributed editorial and financial assistance.

2. *Report of the Editor of the Journal of Sedimentary Petrology* (*Jack L. Hough*).—The *Journal of Sedimentary Petrology* was expanded from an authorized 96 pages per issue to 128 pages per issue (with approval of the council) beginning in June, 1957. This was necessary to accommodate a large backlog of manuscripts which had been accepted for publication. By the end of the year the backlog of manuscripts was reduced to a satisfactory size, and no further increase in

	Articles		Notes		Discussions		Reviews		S.E.P.M. Data[1] Pages	Advertising[2] Pages	Other[3] Pages	Total Pages
	No.	Pages	No.	Pages	No.	Pages	No.	Pages				
1. (Mar.)	7	86	—	—	—	—	—	—	2	1½	2½	92
2. (June)	12	101	—	—	2	6	1	1	19	½	4½	132
3. (Sept.)	12	115	1	4	1	5	1	2	—	½	1½	128
4. (Dec.)	11	114	—	—	1	2	—	—	5	1½	4½	132
Total	42	416	1	4	4	13	2	3	26	4	18	484

[1] Including announcements of meetings, programs, minutes of annual meeting, revised Constitution and By-laws.
[2] Exclusive of advertisements on cover.
[3] "Other" includes title pages, index, errata, and a 2-page memorial.

size appears to be needed in the near future.

The *Journal* was published in 1957 as Volume 27, Numbers 1 through 4. A summary of the contents is given in the table at the top of the page.

The membership list of the Society of Economic Paleontologists and Mineralogists was omitted from Volume 27, in order to save space for technical articles, but it will be published in Volume 28.

The national origins of the articles, notes, and discussions are as follows:

United States	35
England	3
India	3
Italy	2
Argentina	1
Canada	1
France	1
Switzerland	1

As in the past eight years, the University of Illinois has provided a part-time editorial assistant.

3. *Report of the Secretary-Treasurer* (Samuel P. Ellison, Jr.)—

MEMBERSHIP, MAILING, AND JOURNAL STATISTICS

	Dec. 31, 1957	*Dec. 31, 1956*	*Dec. 31, 1955*
1. S.E.P.M. Membership:			
Active Members	1,085	990	895
Associates	319	292	285
Correspondents	6	5	5
Honorary Members	3	3	3
	1,413	1,290	1,188
2. *Journal of Paleontology* Mailing List:			
S.E.P.M. Active & Honorary Members	528	509	485
S.E.P.M. Associates	160	150	155
Subscribers	840	810	722
P.S. Members	638	624	610
	2,166	2,093	1,972
3. *Journal of Sedimentary Petrology* Mailing List:			
S.E.P.M. Active & Honorary Members	721	677	607
S.E.P.M. Associates	207	184	171
S.E.P.M. Correspondents	6	5	5
S.E.P.M. Subscribers	979	890	806
	1,913	1,756	1,584
4. Edition of *Journal of Paleontology*	2,400	2,400	2,200
5. Edition of *Journal of Sedimentary Petrology*	2,400	2,100	1,900
6. Number of Pages, *Journal of Paleontology*	1,190	1,394	1,084
7. Number of Plates, *Journal of Paleontology*	150	146	108
8. Number of Pages, *Journal of Sedimentary Petrology*	484	386	317
9. New Members	150	137	161
10. Transfers to Active Membership	49	41	47
11. Members and associates dropped for non-payment of dues, 1/1/58	49	17	16

The Council, Society of Economic Paleontologists and Mineralogists:

We have examined the balance sheet of Society of Economic Paleontologists and Mineralogists at December 31, 1957, and the related statement of income and surplus for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the accompanying balance sheet and statement of income and surplus present fairly the financial position of Society of Economic Paleontologists and Mineralogists at December 31, 1957, and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

ARTHUR YOUNG & COMPANY

Tulsa, Oklahoma, January 20, 1958

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
BALANCE SHEET, DECEMBER 31, 1957

ASSETS	*Total*	*General Fund*	*Publication Fund*
CURRENT ASSETS:			
Cash	$26,765.03	$20,711.06	$6,053.97
Savings account	2,745.84	2,745.84	—
Accounts receivable	550.61	499.61	51.00
Total current assets	$30,061.48	$23,956.51	$6,104.97
PUBLICATIONS:			
Journal of Paleontology:			
Issues prior to 1957—11,114 journals at $0.50 each (1,715 complete volumes)	$ 5,557.00	$ 5,557.00	$ —
Issues 1 to 6 of 1957—1,144 journals, at cost	2,462.61	2,462.61	—
Reprints in 1948, Volume 1, 1927—675 volumes, at cost	1,470.02	1,470.02	—
Journal of Sedimentary Petrology:			
Issues prior to 1957—2,687 journals at $0.50 each (761 complete volumes)	1,343.50	1,343.50	—
Issues 1 to 4 of 1957—1,998 journals, at cost	2,150.46	2,150.46	—
Special publications:			
Turbidity Currents, 230 copies, at cost	196.67	—	196.67
Recent Marine Sediments, 642 copies, at cost	1,324.77	—	1,324.77
Finding Ancient Shorelines, 259 copies, at cost	452.68	—	452.68
Regional Aspects of Carbonate Deposition, 555 copies, at cost	1,238.98	—	1,238.98
Total publications	$16,196.69	$12,983.50	$3,213.10
FURNITURE AND FIXTURES (less reserve, $1,793.84)	$ 1.00	$ 1.00	$ —
DEFERRED CHARGES	$ 313.99	$ 313.99	$ —
	$46,573.16	$37,255.09	$9,318.07
LIABILITIES AND SURPLUS			
CURRENT LIABILITIES:			
Accounts payable	$ 164.05	$ 157.10	$ 6.95
Amount payable to Paleontological Society	4,646.05	4,646.05	—
Total current liabilities	$ 4,810.10	$ 4,803.15	$ 6.95
DEFERRED CREDITS:			
Subscriptions to Journals—net of portion to be received by Paleontological Society	$ 8,817.03	$ 8,817.03	$ —
Membership dues for 1958	9,492.00	9,492.00	—
Total deferred credits	$18,309.03	$18,309.03	$ —
SURPLUS, per accompanying statement	$23,454.03	$14,142.91	$9,311.12
	$46,573.16	$37,255.09	$9,318.07

4. *Report of the Research Committee (H. A. Ireland, Chairman).*—Membership of the Committee, with terms ending at the annul meeting of each year as indicated, consists of the following: 1958- W. J. Plumley, R. R. Shrock, W. H. Akers, Eli Mencher; 1959—R. V. Hollingsworth, S. A. Levinson, D. L. Inman, V. E. Barnes, A. R. Loeblich, H. H. Murray; 1960—G. E. Murray, L. M. Cline, W. D. Pye, H. A. Ireland, and S. G. Wissler.

At the annual meeting of the 1957 Research Committee on April 1, in St. Louis, Curt Teichert, the preceding chairman, turned over the Committee to H. A. Ireland. Plans were laid for the committee

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
STATEMENT OF INCOME AND SURPLUS
YEAR ENDED DECEMBER 31, 1957

	Total	*General Fund*	*Publication Fund*
INCOME:			
Membership dues and subscriptions:			
Journals of Paleontology and Sedimentary Petrology	$ 4,090.00	$ 4,090.00	$ —
Journal of Paleontology	15,227.90	15,227.90	—
Journal of Sedimentary Petrology	8,873.04	8,873.04	—
	$28,190.94	$28,190.94	$ —
Sales of special publications:			
Turbidity Currents	$ 372.98	$ —	$ 372.98
Recent Marine Sediments	911.00	—	911.00
Finding Ancient Shorelines	571.10	—	571.10
Regional Aspects of Carbonate Deposition	7,196.80	—	7,196.80
	$ 9,051.88	$ —	$9,051.88
Sales of back numbers:			
Journal of Paleontology, Volumes 1 to 31	$ 6,806.50	$ 6,806.50	$ —
Journal of Sedimentary Petrology	885.10	885.10	—
	$ 7,691.60	$ 7,691.60	$ —
Sales of plates	$ 784.57	$ 784.57	$ —
Advertising	$ 502.25	$ 502.25	$ —
Convention income	$ 282.36	$ 282.36	$ —
Donations (including $1,840.00 from The American Association of Petroleum Geologists)	$ 5,136.77	$ 5,136.77	$ —
Miscellaneous	$ 348.12	$ 348.12	$ —
	$51,988.49	$42,936.61	$9,051.88
Less: Portion of 1957 income accrued to Paleontological Society	4,386.90	4,386.90	—
	$47,601.59	$38,549.71	$9,051.88
COSTS AND EXPENSES:			
Cost of printing:			
Journal of Paleontology	$14,642.10	$14,642.10	$ —
Journal of Sedimentary Petrology	9,895.81	9,895.81	—
Regional Aspects of Carbonate Deposition	5,563.15	—	5,563.15
	$30,101.06	$24,537.91	$5,563.15
Expenses:			
Clerical salaries	$ 7,867.00	$ 7,867.00	$ —
Office supplies	616.05	616.05	—
Postage and express	1,722.57	1,585.09	137.48
Office rent	2,000.00	2,000.00	—
Telephone	42.06	42.06	—
Audit fee	210.00	210.00	—
Payroll taxes	172.47	172.47	—
Miscellaneous	1,401.11	935.23	465.88
	$14,031.26	$13,427.90	$ 603.36
Adjustment for increase in inventory of publications	$ (632.50)	$ (323.56)	$ (308.94)
	$43,490.82	$37,642.25	$5,857.57
NET INCOME	$ 4,101.77	$ 907.46	$3,194.31
SURPLUS AT DECEMBER 31, 1956	19,352.26	13,235.45	6,116.81
SURPLUS AT DECEMBER 31, 1957	$23,454.03	$14,142.91	$9,311.12

activity for 1957–1958. The organization of the Research Committee Symposium on *Silica in Sediments* for 1958 was discussed concerning subject matter and possible participants. Only a year was available in which to organize the symposium. A new policy was established and approved by the Council providing for a Vice-Chairman to organize a symposium for two years hence. Grover E. Murray was appointed Vice-Chairman and after discussion the subject of "Classification of Sedimentary Units" was tentatively selected for the symposium for 1959. This new policy allows two years for preparation of the annual symposium.

The second symposium session generally

reserved for the President's organization was merged with the session allotted to the Research Committee to allow a full day for Silica in Sediments. It was decided to recommend publication of the symposium as a Special Publication, and the Chairman was authorized to collect the papers and edit them. A deadline of September 15 was set for all papers to be in hand for the publication.

Following the meeting in St. Louis, the Chairman proceeded with solicitation of the committee for men doing research on silica and most of the participants on the symposium were committed by June. The papers cover sources, occurrence, solution, deposition, diagenesis, geochemistry, and regional examples and studies of silica in sediments. A panel discussion including all participants will follow the symposium.

The Research Committee nominated Charles E. Decker, Marcus A. Hanna, and Hans E. Thalmann to be elected as Honorary Members of the Society. They were approved by the council and notified by the President. W. J. Hilseweck, Henry V. Howe, and U. S. Grant, IV, respectively, were requested by the President to make the citations and presentations in Los Angeles in March, 1958.

The Research Committee selected for the Best Paper Award for the *Journal of Paleontology* for 1956 the article, "The Evolution of Some Upper Cambrian and Lower Ordovician Trilobite Families," by Christina Lochman-Balk. The Best Paper Award for the *Journal of Sedimentary Petrology* was "Organic Sedimentation in Warnbro Sound, Western Australia," by Maurice A. Carrigy. Presentation of a citation and certificate to each recipient will be made by H. A. Ireland at the Business Meeting of the S.E.P.M. in Los Angeles.

The Research Committee held its final meeting at the Biltmore Hotel on Monday, March 10, at 10:30 A.M. Members present were: H. A. Ireland, S. A. Levinson, Hayden Murray, Grover Murray, Virgil Barnes, L. M. Cline, A. R. Loeblich, Robert R. Shrock, William J. Plumley, Douglas Inman, Ely Mencher. Others present were Heinz Lowenstam who will become a new member of the committee and incoming S.E.P.M. President and Secretary-Treasurer, Gordon Rittenhouse and Raymond E. Peck.

The Committee nominated Henryk B. Stenzel for Honorary Membership and will recommend his election by the Council. It also requested incoming President Rittenhouse to notify him as soon as possible.

The Committee voted to request the approval of the Council for publication of the 1958 Symposium, "Silica in Sediments," to be edited by H. A. Ireland.

It was decided that the Research Committee Symposium for 1960 will be entitled, "Relation of Paleontology and Mineralogy to Polar Wandering and Continental Drift." This will be under the direction of Arthur Munyan.

5. *Report on the Earth Sciences Division of the National Research Council* (*Francis J. Pettijohn, S.E.P.M. Representative*).—The Division's activities are (1) advising other federal agencies (National Science Foundation, etc.), (2) conducting conferences on special topics, and (3) organization of technical committees.

Of special interest are the six advisory committees that screen applications for fellowships. The support given for earth science education and research is most important and such support cannot be properly allocated without the work of these committees.

Conferences on tektites, on clay minerals, and on basalt were conducted under Division auspices. The proceedings of the conferences on tektites and clay minerals will be published. A conference on arctic sea ice is scheduled for early 1958.

The Committee on Marine Ecology and Paleoecology has completed its work. The results are embodied in the two volumes which have been issued as Memoir 67 by the Geological Society of America. A new Committee on Oceanography, interdivisional in membership, has been organized to assume leadership in the advancement of the marine sciences and to provide guidance to the federal agencies in their studies of the ocean. The Committee on the Glacial Map of the United States is preparing a new glacial map to supersede that published by the Geological Society of America in 1945. The two technical committees mentioned above plus the Committee on Clay Minerals are

perhaps those of greatest interest to the members of S.E.P.M.

6. *Report on the American Geological Institute* (*Robert R. Shrock*).—Now that *GeoTimes* is being sent to more than 20,000 earth scientists in North America, including all members of S.E.P.M., our membership is kept informed of the many different activities, projects, future plans, and present problems of the American Geological Institute. There is no need, therefore, to report in detail on any of these particular activities.

Your representative attended the meeting of the Board of Directors of A.G.I. in Atlantic City, November 6, 1957. From the usual reports of officers and committees came four items of special interest to our membership.

(1) As a result of a vigorous program carried out by loyal and hard-working officers of A.G.I., the Institute is in the black for the first time, thanks to a $20,000 grant from the National Science Foundation, and increases in the number of Industrial Associates and in the number of the "Committee of 100." Even with this support, however, as well as the tithes from most of the member societies, the Institute does not yet have a guaranteed continuing adequate income. Though lessened somewhat, the problem of adequate support on a continuing basis is still a major one to be solved if the Institute is to continue publication of *GeoTimes* and to carry on even a reasonable number of the many services that members of the member societies would like to see offered by A.G.I.

(2) *GeoTimes*, now going free to some 20,000 earth scientists, is read widely and has gained wide acceptance as spokesman for our profession. It has been quite influential in advertising several publications and in providing advanced publicity for the very successful "Geology Month" for the Boy Scouts. It is hoped that *GeoTimes* can be sent ultimately to all of the 30,000 earth scientists who are interested enough in this broad area to want to receive it.

(3) *The Glossary of Geology and Related Sciences*, A.G.I.'s first major publication, and entirely an A.G.I. affair so far as preparation was concerned, proved an immediate financial success. The manuscript went to press in late February, 1957, and the first printing of 5000, out in May, was exhausted in July. A second printing of 5000 was ordered and completely paid for and more than 1700 copies of the second printing have already been sold.

With funds now available in the Publication Fund, the A.G.I. will soon bring out a new edition of the "Career Booklet" and expects to distribute some 50,000 copies of this edition in the next two or three years. The Institute also recently brought out a new edition of the "Directory of Departments of Geological Sciences" and, thanks to the A.A.P.G., will soon bring out, as an A.G.I. publication, the second edition of the "Directory of Geological Information." The Institute will soon have in press Max Pangborn's "Earth for the Layman" which is an index of popular books on the earth sciences. All of these are service publications and together constitute one of the more important activities of the Institute.

(4) The Institute, through its membership and *GeoTimes*, took an active and effective part helping the Boy Scouts in the Geology Month of October, 1957.

In addition to the very important problem of getting A.G.I. on a sound financial basis is the second problem of keeping the Institute a tax-free organization. For many reasons that cannot be presented here because of space limitation, the officers of the Institute are fully convinced that it must continue to retain this tax-free basis even though this means that the Institute cannot engage in lobbying, nor can it try to influence public boards or commissions. Consequently, the Institute is prevented from carrying out many kinds of activities that members of the member societies have brought to the attention of the officers and Board of Directors. Chief among these perplexing challenges is that of the problem of licensing geologists and geophysicists.

Your representative came away from the meeting with the feeling that although the A.G.I. is on firmer ground than ever before, its long-term financial problems still await solution. *GeoTimes* is growing in its influence and effectiveness in representing our profession, but will need continued financial support. There are many old and new perplexing problems that lie ahead for future Boards of Directors. It is also your repre-

sentative's opinion that the Institute is well worth the continued support of our own Society.

It is strongly suggested that the S.E.P.M. Council give serious consideration to the matter of bringing the terms of service of its directors into better agreement with the operating year of the A.G.I., so that there is no misunderstanding as to the responsibilities of incoming and outgoing S.E.P.M. officers. A similar suggestion was included in the 1957 report of Past-President Francis J. Pettijohn.

7. *Report of the S.E.P.M. Representative to the A.G.I. Government Relations Committee (Norman S. Hinchey).*—The A.G.I. Government Relations Committee met in Atlantic City, New Jersey, on November 5, 1957.

The subjects discussed at the committee meeting are briefly noted below. No formal action was taken and as a result nothing was formally referred to the Executive Committee of A.G.I.

(1) The problem of the Antiquities Act that has been of concern to the Society of Vertebrate Paleontology was discussed. It was the consensus that care should be taken by the S.V.P. Committee that new rules and regulations be set up in such a way that they not serve to block private geologists in the course of normal field work.

(2) The problem of reimbursement of travel expenses of U. S. Geological Survey personnel on Distinguished Lecture tour was discussed. Dr. Stephenson reported that A.G.I. is cooperating with the American Institute of Biological Sciences in an attempt to develop a workable policy with the Comptroller General.

(3) American Geological Institute continues to be the registering agency for the nation and hopes to be able in the future to use the registry data for statistical studies of the profession.

(4) The joint meeting with A.A.P.G. National Responsibilities Committee, last spring in St. Louis, was discussed. It was the consensus that liaison between the two committees was highly desirable and that a member or members of our committee might sit as observers at the annual meeting of the A.A.P.G. committee.

(5) Dr. Stephenson reviewed progress on the problem of the definition of research in the Earth Sciences as used by the National Science Foundation. The N.S.F. requested a committee of the American Petroleum Institute to meet with the Bureau of Labor Statistics and it was agreed that fundamental field exploration be classed as research. However, it was found so difficult to operate the new definition that it was agreed to go back to the Harvard Business School definition for this year, with the hopes that a new and workable definition can soon be developed.

(6) The *ad hoc* Committee on Licensing was scheduled to meet with our committee but due to a series of circumstances did not do so. Dr. George E. Ekblaw, chairman of that committee, prepared a general statement and will welcome comments from any of the members of our committee.

(7) Dr. Meyerhoff discussed current activities of SMC–EMC and the Reserve Act. Under the new plan the military will take only 2000 scientists and engineers per year; they will be assigned a service; and their duty in uniform will be reduced to three months. The December number of *Geo-Times* will contain a column describing this new plan.

8. *Report of the Joint Committee on Invertebrate Paleontology (Raymond C. Moore).*—Progress in the organization of volumes planned for the *Treatise on Invertebrate Paleontology* has been retarded during the past year for several unavoidable reasons, chief of which has been delay in completion of assigned segments for various contributing authors. Nevertheless, typescript and materials for illustrations have steadily been accumulating with distribution to their appropriate divisions so as to be ready when other needed parts are available.

The volume next to appear in the series will be part "O," Arthropoda 1, on trilobites and related forms. Typesetting is begun for this section, but appearance of the volume cannot be earlier than late in 1958. Size will be comparable to that of the last published Parts on Coelenterata and Ammonoidea.

Typescript for nearly all of Part "I," Mollusca 1, treating chitons, scaphopods, and all Paleozoic gastropods is in hand and nearly all illustrations have been prepared. Expected readiness of the Parts on foraminifers and ostracodes has not been realized.

It is appropriate to record, with deep re-

gret, the loss by death of several contributing authors—Austin H. Clark, L. M. Davies, Emma Richter, Rudolf Richter, W. K. Spencer, Merrill Stainbrook, O. W. Tiegs, J. Wanner, T. H. Withers, and Arthur Wrigley. At least part of the contribution expected from each of the authors except Dr. Clark and Dr. Stainbrook had been received prior to their death.

There is need to push ahead the task of completing unfinished volumes.

9. *Report of the Permian Basin Section (W. A. Waldschmidt).*—The Permian Basin Section will have completed its fourth year at the close of its third annual meeting which is to be held at the Scharbauer Hotel in Midland, Texas, on March 28 and 29, 1958. Arrangements will be made to begin registration on the afternoon of March 27. For this meeting, J. P. D. Hull, Jr. is general chairman and Edward A. Vogler is co-chairman. The technical program is being arranged by Donald A. Zimmerman, chairman, and his co-chairman, G. A. Sanderson.

Present officers of the Permian Basin Section are: W. A. Waldschmidt, President; Wayne W. Roye, 1st Vice-President; Donald A. Zimmerman, 2nd Vice-President; M. R. Stipp, Secretary; and Booker L. McDearmon, Treasurer. Balloting for officers will not be completed until March 1; consequently, the names of the Executive Committee members for the ensuing year will have to be announced at a later date.

Shortly after the present Executive Committee took office, the sale of all publications of the Permian Basin Section was delegated to the Microviolite Company, 420 West Texas Street, Midland, Texas.

The annual field trip of the Permian Basin Section will be held April 10, 11, and 12 on the "Cretaceous Platform and Geosyncline, Culberson and Hudspeth Counties, Trans-Pecos Texas." Registration will be at Van Horn, Texas, on the afternoon of April 10, 1958. Wayne W. Roye is general chairman for this trip. The leaders will be Professor Ronald K. DeFord of the University of Texas and Dr. John P. Brand of Texas Technological College. Localities to be studied are in the Apache, Wylie, Van Horn and Indio Mountains.

Membership of the Permian Basin Section in May, 1957, was 285. It is hoped that the number of members will be as large or larger at the close of the third annual meeting.

10. *Report of the Gulf Coast Section (Jack Colle).*—The 1957 year was quite successful under the guidance of President Lloyd Pyeatt. Progress was made and is continuing to be made on the Type Localities Project.

The high light of the year was a field trip held October 18 and 19. This trip covered the Oligocene and portion of the Eocene stratigraphy of western Mississippi, central Louisiana, and eastern Texas. Numerous localities were visited and sampled by approximately seventy-five members of the S.E.P.M. Fred Smith, Professor of Geology at Texas A. & M. College, led the field trip and is due considerable credit for his excellent work. An important event was a night meeting at Alexandria, Louisiana. Professor Clarence O. Durham of the Louisiana State University School of Geology was the principal speaker, reporting on recent work that he and other staff members have accomplished in field studies in central and northern Louisiana. The annual field trip guide book is available through Jack Colle, 911 San Jacinto Building, Houston, Texas.

The annual meeting of the Section was held in New Orleans November 6 through 8, 1957. The first day of the two-day Technical Session was a joint meeting with the Gulf Coast Association of Geological Societies. The second day, the section held its own technical session concurrently with the other meeting. A number of interesting papers were presented.

The annual business meeting was held at the close of the Technical Session with President Pyeatt presiding. Following reports of the various officers and committee chairmen, there was a discussion of various projects that are in progress and will be pursued during the coming year. Mr. Pyeatt thanked his officers and the membership for their cooperation during the year. The meeting was turned over to the new president, Jack Colle. After a few words by the incoming president, the meeting was adjourned.

11. *S.E.P.M. President's Report (R. V. Hollingsworth).*—The financial position of the Society is improving although finances remain our most serious problem. The General Fund showed a profit of $907.46 in 1957 as compared with a loss of $637.17, in

1956. Had it not been for a donation of $1800 from the A.A.P.G. and $282.36 from the St. Louis Convention, we would have shown a loss of $1174.90. Also, we received a donation from C. W. Tomlinson and the University of Kansas of $1296.77 toward the payment of engraving the *Journal of Paleontology* without which our loss would have amounted to $2471.67. The Publication Fund showed a profit of $4101.77 in comparison with a profit of $1860.88 for 1956 and is in fairly good shape for future spending on Special Publications. Printing costs have substantially increased and their effect upon our financial status will be approximately offset by the increase in dues which was approved in the Business Meeting at St. Louis and will be reflected in our 1958 income.

The *Journal of Paleontology* and the *Journal of Sedimentary Petrology* are both receiving increased recognition. These journals are a primary reason for the existence of the Society and are its most important activity. The special donation of $1800 from the A.A.P.G. permits the *Journal of Sedimentary Petrology* to publish an increased number of papers and thus reduce the backlog and shorten the prepublication waiting period. However, other income must be found to enable our journals to continue to flourish, meet the future demands upon them, and to meet the rising costs of printing.

Our membership again increased about ten per cent in 1957 and this seems to be about the normal rate of growth, which indicates that new measures should be taken toward a solution of the problem of how to stimulate our growth. A concentrated effort made by several individual members, particularly Jack L. Hough at the University of Illinois, produced good results but did not increase the percentage rate of growth and our total membership is far below what it should be to support our program of activities. Our Technical Program continues to be an important part of the annual joint meeting with the A.A.P.G. and our participation is much greater than would be inferred from relative membership figures. At the 1957 St. Louis meeting our Society presented 25 papers compared with 28 by A.A.P.G. and this year the comparable figures are in about the same proportion, 31 and 34 respectively. This record indicates the growing importance of our Society and should serve as a stimulus to our membership to make a concerted effort to get new members.

Further recognition of the importance of the Research Committee has been made by putting into effect the plan recommended by a special committee and approved by the council whereby the subjects of the symposia are determined two years in advance and the ultimate chairman of the symposium is appointed vice-chairman two years in advance in order to provide adequate time to organize the symposium. Outstanding work by H. A. Ireland as chairman during this initial year of the new plan has provided the basis for this procedure to operate successfully and make it possible to have the manuscripts in hand at the time of the meeting to permit arrangements for publication to follow expediently.

Especial services were rendered during the year by the following members and I offer them my sincerest thanks: (1) the various chairmen and co-chairmen of the technical sessions of the annual meeting; (2) Vice-President Stuart A. Levinson, who had the primary responsibility for the Los Angeles Technical Program, particularly for extraordinary performance of unexpected duties; (3) the two nominating committees which consisted of R. Dana Russell, chairman, W. A. Waldschmidt and J. D. Bainton, and Brooks F. Ellis, chairman, Lloyd M. Pyeatt, and Bernhard Kummel; (4) J. D. Bainton as Vice-Chairman for S.E.P.M. and member of the Central Committee for the 1958 joint annual meetings in Los Angeles; (5) H. A. Ireland as chairman of the Research Committee and organizer of the 1958 Symposium on Silica in Sediments and Grover E. Murray as 1958 vice-chairman and chairman and organizer for the 1959 symposium on a subject dealing with the classification of sedimentary units; (6) W. D. Keller as chairman of the Best Paper Awards committee for the Los Angeles meeting; (7) Norman Hinchey as representative to the Government Relations Committee of the A.G.I.; (8) Francis Pettijohn as representative to the National Research Council; (9) R. C. Moore as S.E.P.M. representative on the committee for the preparation of the Treatise on Invertebrate Paleontology; (10) Daniel A. Busch as chairman of the Resolu-

tions Committee for the annual meeting; and particularly (11) Robert H. Dott and Mrs. Ruth Tener, the Society's efficient business manager and Headquarters secretary, respectively, for their valuable services to the Society in all its functions.

An addition to the S.E.P.M. By-Laws was presented by Secretary-Treasurer Ellison. It is suggested that the following be inserted as Article XI and the present Article XI be changed to Article XII.

ARTICLE XI. PUBLICATIONS COMMITTEE

1. The membership of this committee shall consist of five members, including a chairman, three other members, and the chairman of the Research Committee as an ex-officio member. The tenure of office of the chairman and members shall be two years. Membership of the committee shall be appointed by the president from members and associates of the Society.

2. The duties of the Publications Committee shall be to recommend to the council manuscripts or symposia which merit consideration as S.E.P.M. special publications. The Publications Committee shall further recommend type of reproduction, number of copies, and cost figures of manuscripts or symposia.

3. Upon approval of the council, this committee, with the appropriate Society editor or editors, shall edit (or have edited) and publish these manuscripts or symposia.

4. The activities of this committee will include recommending to the council suggestions for improving the quality of our Society Journals consistent with the budgeted monies allotted for publication.

It was moved, seconded, and carried that the above Article be added to our By-Laws.

Acting President Levinson called for new business and Mr. R. Dana Russell stated that the pool of presidential candidates should be further enlarged. It was moved, seconded, and carried that a committee be appointed by the incoming president to study the problem and report to the meeting next year.

The meeting was turned over to incoming President Gordon Rittenhouse.

The Resolutions Committee, composed of Daniel A. Busch, chairman, Orville L. Bandy, and Robert E. King, presented the following "Resolutions of Thanks."

BE IT RESOLVED THAT in behalf of the Society we extend an expression of our sincere thanks to the following:

TO STUART A. LEVINSON, technical program chairman, for his general supervision and handling of the entire technical program;

TO JACK D. BAINTON, S.E.P.M. vice-chairman. for his capable attention to the many details of the meeting;

TO H. A. IRELAND, chairman of the Research Committee, and GROVER E. MURRAY, vice-chairman, for preparing the Research Symposium, "Silica in Sediments";

TO WILBURN H. AKERS and CHARLES M. GILBERT for arranging the papers on paleontology and stratigraphy, and on sedimentary petrology and mineralogy, respectively;

TO the following S.E.P.M. representatives on special committees,—E. L. WINTERER, EDWARD B. FRITZ, W. THOMAS ROTHWELL, and M. M. WHITE;

TO LEO R. NEWFARMER, general chairman, MASON L. HILL, general vice-chairman, JOHN T. HAZZARD, A.A.P.G. program chairman, and to the chairmen and members of all the convention sub-committees, for their efforts in the organization of the Los Angeles meeting;

TO THE EXECUTIVE COMMITTEE of the A.A.P.G., for appropriating $2000.00 as office rent for the Society Headquarters at Tulsa, for the donation of $1800.00 in order that our *Journal of Sedimentary Petrology* could be enlarged for the year 1957, and for sharing the net income from the 1957 St. Louis Convention;

TO ROBERT H. DOTT, for his continued guidance in his capacity as Business Manager of the S.E.P.M.;

TO OUR EDITORS, M. L. THOMPSON and JACK L. HOUGH, for a "job well done" in editing our two publications—the *Journal of Paleontology* and *Journal of Sedimentary Petrology;*

AND TO THE BILTMORE HOTEL, for providing excellent convention headquarters facilities.

The meeting adjourned at 2:30 P.M.

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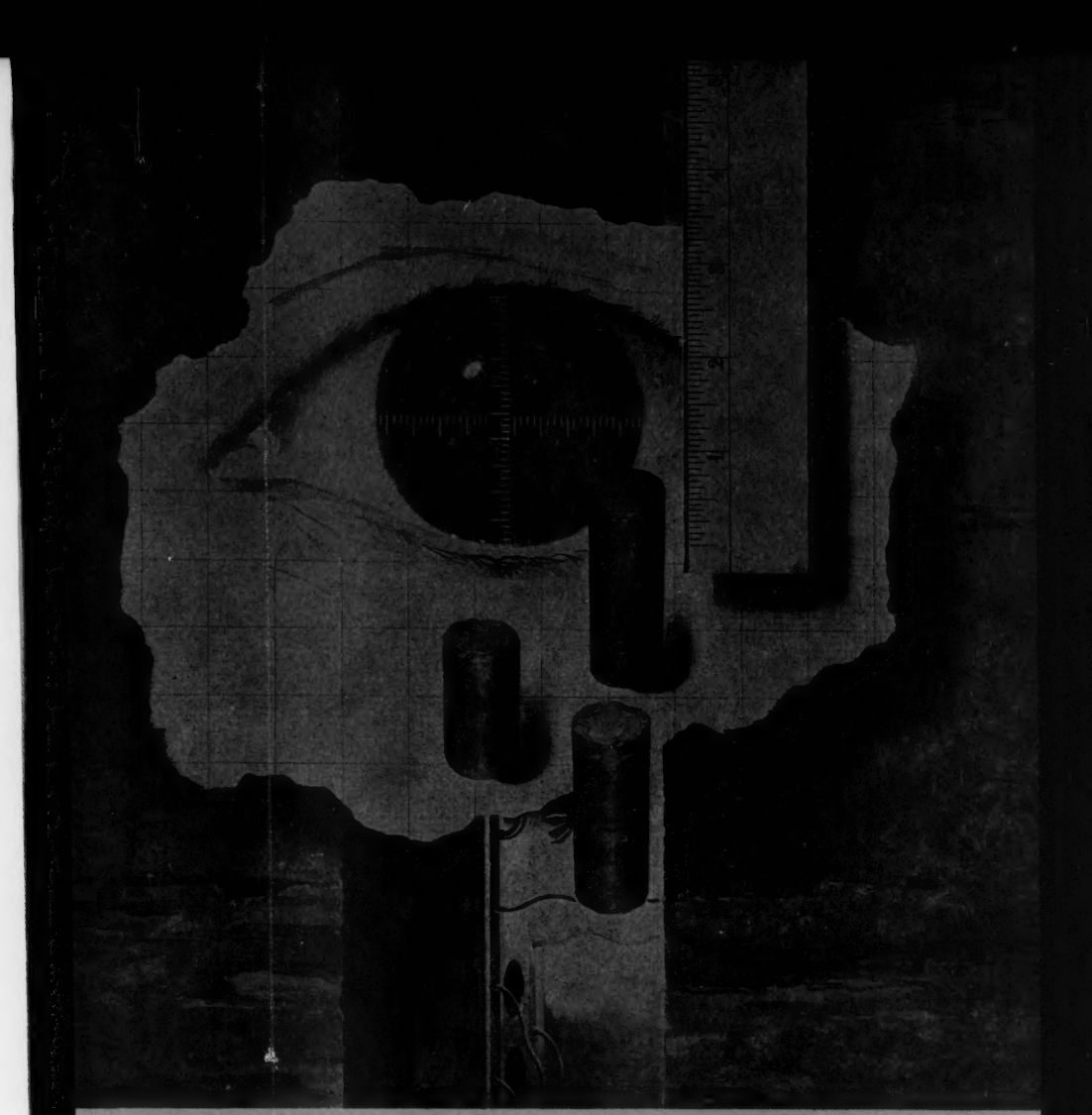

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